An application of ecosite mapping to assess land sensitivity to forest harvesting in the Corner Brook Lake watershed, western Newfoundland

A.R. van Kesteren

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ABSTRACT

The Corner Brook Lake watershed in western Newfoundland is the source of municipal and industrial water supplies for the city of Corner Brook. Forestry Canada was requested to provide assistance to a monitoring committee to facilitate in the planning and operations for industrial timber harvesting in the watershed.

A land sensitivity assessment of the watershed was undertaken through an application of ecosite mapping concepts common to current Canadian ecological land classification practice. Ecosites were delineated as homogenous pedologic, geomorphologic and hydrologic land units using conventional air photo interpretation. Additionally, a simple provisional water yield assessment based on ecosite rankings was undertaken to address water supply concerns.

Ecosite mapping of the watershed area, approximately 90 km^2, was produced at an operational scale of 1:12 500. Maps were digitized and entered into a GIS to aid in application of the data base. Mapping and analysis resulted in the following percentage of land sensitivity levels for the watershed:

Sensitivity Level	% of Watershed Area
L_0 (none)	15.63
L_1 (low)	1.26
L_2 (moderate)	31.53
L_3 (high)	39.33

RÉSUMÉ

Le bassin hydrographique du lac Corner Brook, à l'ouest de Terre-Neuve, approvisionne en eau la municipalité et les industries de Corner Brook. On a demandé à Forêts Canada d'offrir son aide au comité de surveillance de la planification et de l'exploitation de la récolte industrielle du bois dans ce bassin hydrographique.

On a évalué la sensibilité des terres du bassin en appliquant des concepts de cartographie des écosites couramment utilisés pour la classification écologique des terres au Canada. Par la lecture de photos aériennes conventionnelles, on a catégorisé ces écosites par unités de territoire pédologiques homogènes, géomorphologiques et hydrologiques. En outre, pour répondre aux préoccupations sur l'approvisionnement en eau, on a mené une évaluation élémentaire provisoire de l'apport d'eau du bassin à partir du classement des écosites.

On a produit des cartes (échelle : 1/12 500) des écosites de la zone du bassin hydrographique, qui couvre environ 90 km^2. Une fois ces cartes numérisées et introduites dans un système SIG, on leur a appliqué la base de données. Les cartes et l'analyse ont produit les pourcentages suivants de degré de sensibilité des terres du bassin hydrographiques :

Degré de sensibilité	% du bassin hydrographique
L_0 (aucun)	15,63
L_1 (minime)	1,26
L_2 (moyen)	31,53
L_3 (élevé)	39,33

L_4 (very high)	7.26
L_5 (extreme)	4.99

All land in the L_5 class and 9.40% of land in the L_4 class representing 5.67% of the full watershed area was recommended for exclusion from harvest operations.

A provisional water yield assessment was conducted for the full watershed area and for the Eastern Lake subcatchment area. Results of these analyses follow:

Sensitivity Level	% of Water Yield (full watershed)
L_0 (none)	83.39
L_1 (low)	0.06
L_2 (moderate)	1.69
L_3 (high)	8.26
L_4 (very high)	2.84
L_5 (extreme)	3.76

Sensitivity Level	% of Water Yield (Eastern Lake)
L_0 (none)	88.07
L_1 (low)	0.03
L_2 (moderate)	0.82
L_3 (high)	6.12
L_4 (very high)	2.40
L_5 (extreme)	2.56

It is generally concluded that watershed and forestry management objectives for the Corner Brook Lake watershed are compatible subject to careful planning and implementation of operational guidelines.

L_4 (très élevé)	7,26
L_5 (extrême)	4,99

Il a été recommandé que toutes les terres de la catégorie L_5 et 9,4 % de celles de la catégorie L_4, représentant 5,67 % de l'ensemble de la zone du bassin hydrographiques, soient exclues des activités de récolte.

Une évaluation provisoire de l'apport d'eau a été menée pour l'ensemble de la zone du bassin hydrographique et pour la zone du sous-bassin de drainage du lac Eastern. Ces analyses ont produit les résultats suivants :

Degré de sensibilité	% d'apport d'eau (ensemble du bassin hydrographique)
L_0 (aucun)	83,39
L_1 (minime)	0,06
L_2 (moyen)	1,69
L_3 (élevé)	8,26
L_4 (très élevé)	2,84
L_5 (extrême)	3,76

Degré de sensibilité	% d'apport d'eau (lac Eastern)
L_0 (aucun)	88,07
L_1 (minime)	0,03
L_2 (moyen)	0,82
L_3 (é'evé)	6,12
L_4 (très élevé)	2,40
L_5 (extrême)	2,56

En conclusion générale, les objectifs de protection du bassin hydrographique et ceux de l'exploitation forestière du bassin du lac Corner Brook sont compatibles, dans la mesure où l'on procédera à une planification soignée et où l'on utilisera des bonnes pratiques de récolte.

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1.0 INTRODUCTION

The Corner Brook Lake watershed (Figure 1) provides municipal and industrial water supplies for the city of Corner Brook. The approximate 90 km^2 of land contains a valuable timber resource within a short hauling distance of a major paper producer in the city.

In March 1988, Forestry Canada was requested to provide assistance and technical input to a watershed monitoring committee. The committee consisted of the following agencies and representatives:

Mr. D. Brown	City of Corner Brook Municipal Council
Mr. K. Sutton	Department of Forestry and Agriculture
Mr. M. Churchill	Corner Brook Pulp and Paper Limited
Mr. I. Bell	Department of Environment and Lands
Mr. L. Moores	Department of Forestry and Agriculture
Mr. B. White	Corner Brook Pulp and Paper Limited
Ms. C. Leeder	Department of Environment and Lands

The committee was mandated to plan and implement decisions on forestry operations in the watershed with particular reference to the legally defined municipal water supply area (Figure 2).

Forest harvesting in the Corner Brook Lake watershed presented three primary concerns:

1. The potential for changes in water quality.
2 The potential for changes in water quantity.
3. The potential for losses in the forest landbase through soil and site degradation.

Harvesting operations inevitably result in soil and site disturbance. Consequently, changes in water quality and quantity may occur. Achieving reductions in soil and site disturbances and maintenance of water quality and supply can be addressed by three general principles:

1. Preplanning of harvest operations.

2. Implementation of site specific operating practices.

3. Implementation of contingency strategies.

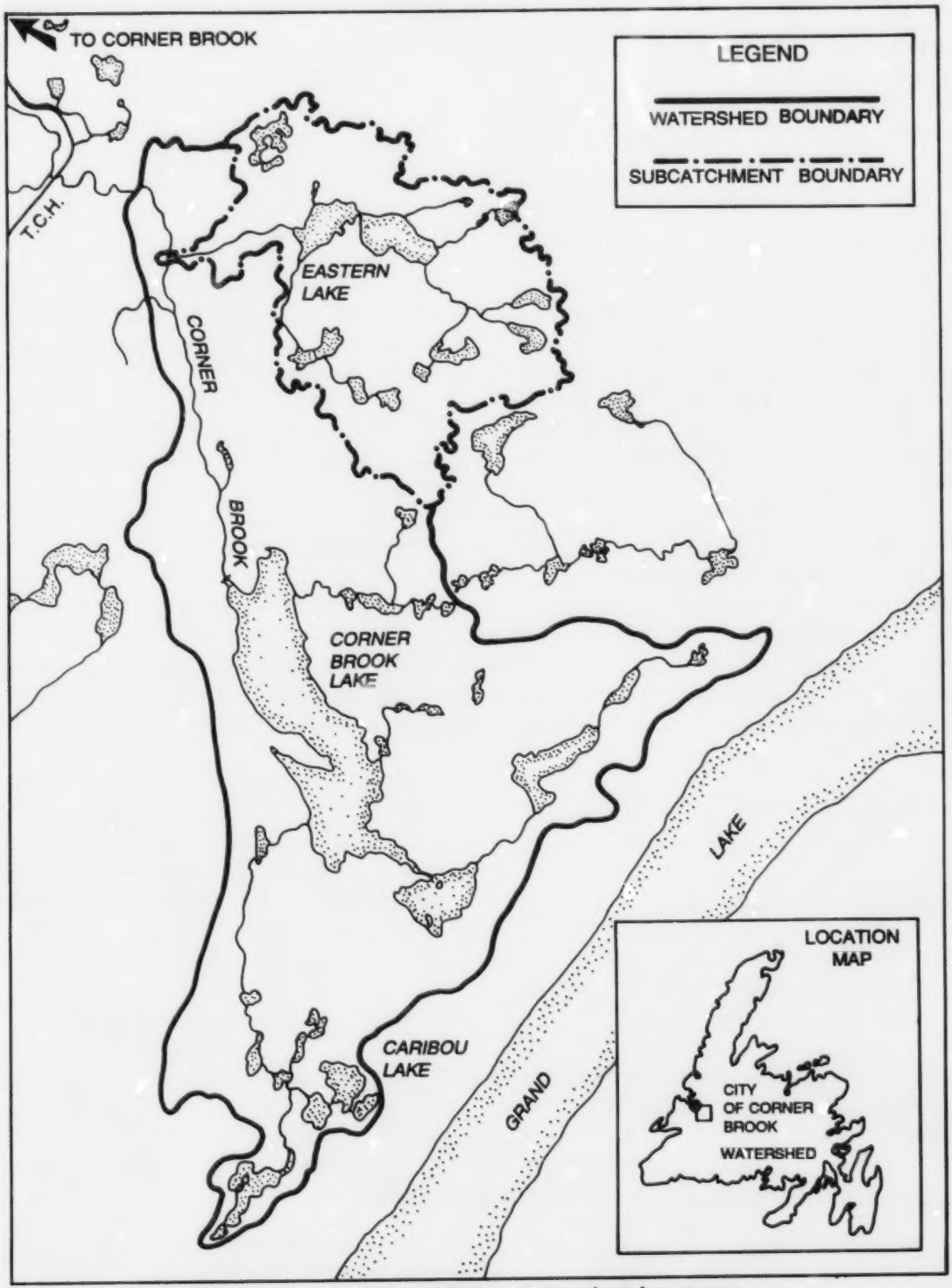


Figure 1. Corner Brook Lake watershed and Eastern Lake subcatchment area.

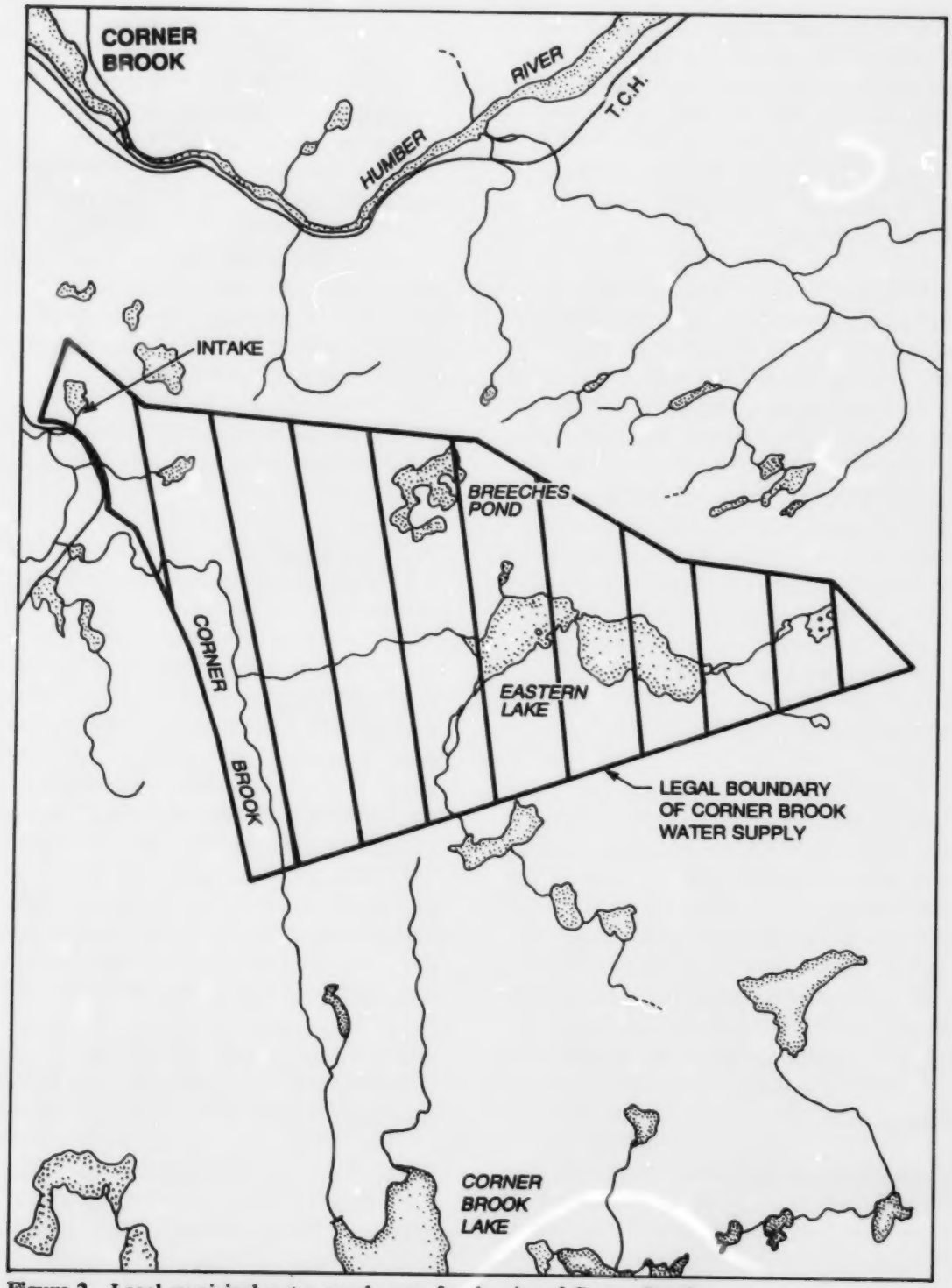


Figure 2. Legal municipal water supply area for the city of Corner Brook.

A land sensitivity assessment was undertaken to serve as a planning data base from which the committee could address the stated concerns and principles.

2.0 APPROACH

2.1 Introduction

The land sensitivity assessment was undertaken through an application of the methodology outlined by van Kesteren (1986). In summary, this method is a land classification system which is used to delineate discrete ecosites for which potential soil and site degradation can be rated. Additionally, sediment delivery potential may be deduced from the classification. A cartographic data base is thus compiled and specific guidelines referenced to the classified ecosite polygons provide a basis for planning, field operations and mitigation of potential site impacts.

2.2 Soil and Site Degradation

It is necessary to distinguish soil and site disturbances and soil and site degradation. Soil disturbances or exposed soils (Case 1978) may be considered as the initial effects of timber harvesting. Some examples of disturbance types would be bulldozed skid trails, secondary extraction roads, and timber landing areas. The intensity and extent of disturbance types on different ecosites, largely determines the magnitude of subsequent soil and site degradation.

Two general types of soil and site degradation can be recognized;

1. Non-erosional.
2. Erosional (i) surface erosion and (ii) mass movements.

Erosional and non-erosional degradation can occur independently, however, non-erosional phenomena often lead to surface erosional effects.

Non-erosional degradation refers to *in situ* changes in the mechanical properties of soils. Associated changes in biological and thermal properties may also occur but these are not considered in this report.

Two basic forms of non-erosional soil degradation can be identified (Standish *et al.* 1988):

1. Soil compaction.
2. Soil puddling (deformation and displacement).

These types of degradation occur as a result of the strength of a soil being exceeded by some compactive force associated with logging machinery. Soil compaction occurs under unsaturated conditions and results in increases of bulk density and related reduction in macro pore space. Under wet and saturated conditions shear strength failure can occur resulting in deformation and displacement. Although these two forms of soil degradation are distinct, under field conditions they often occur as part of a process continuum. Associated with soil compaction and puddling may also be increases in spatial and temporal impoundment of water.

Surface erosion involves the detachment, fluid transport and deposition of soil materials. Three primary surface erosional processes may be identified:

1. Rainsplash erosion.
2. Sheet flow (overland flow) erosion.
3. Rill and gully (channelized flow) erosion.

Although these processes may occur independently they are frequently interrelated. Rainsplash erosion is a process of soil particle detachment resulting from rainfall impact. Sheet erosion occurs as runoff generated from rainfall or snowmelt removes soil particles, resulting in a uniform lowering of a land surface. Often the materials detached from rainfall impact are entrained in the runoff associated with sheet erosion processes. Channelized erosion occurs as sheet flow becomes differentiated into rill flow paths due to random topographic irregularities on land surfaces. This can result in the formation of permanent gullies through rill capture (Horton 1945). Generally, the presence of ground vegetation cover provides high infiltration capacities and sufficient resistance to substantially reduce the erosive power of rainfall and runoff (Patric 1991). Thus, on many ecosites the intensity of natural geologic erosion is in equilibrium with pedogenic processes and soil formation rates. Accelerated erosion often occurs from vegetation removal. In such cases, rates of soil erosion are greater than rates of soil formation, and exposure of soil may result in an area of localized disequilibrium on an ecosite.

Soil compaction and puddling often contribute to surface erosion processes. Compaction can lead to substantial reductions in infiltration capacity. These reductions result in more rapid and often more prolonged generation of surface runoff. Consequently, erosive power is increased with the potential for greater soil loss through sheet and channelized flows. Compaction may also have a tendency to cause some soils to form loosely consolidated blocky structures. These structures can result in an initial resistance to sheet and rainsplash erosion, but may be subject to micro-mass wasting processes and rapid disintegration associated with channelized flow.

Soil puddling may result in initially increased resistance to erosion. This occurs due to displacement of natural soil aggregates or increased infiltration capacities due to soil horizon mixing. However, under the influence of erosive forces from sheet and channelized flows this resistance can be minimal, especially with the coincidence of underlying areas of mechanically compacted or naturally consolidated soil, which provides a significant discontinuity boundary for shearing.

Mass movements may be defined as the downhill transport of surface materials including consolidated bedrock, under the influence of gravitational force but often assisted by buoyancy and lubrification effects of rainfall and/or snowmelt (Whittow 1986). There are many mass movement types but colloquially these phenomena may be collectively referred to as "landslides". The material in these movements acts as a consolidated mass in which close grain to grain contact is maintained. The mass movement process is therefore distinguishable from typical surface erosional processes generated by runoff where there is fluid transport of material.

Mass movements are a threshold phenomenon which can be related to a number of factors. Frequency of occurrence may be correlated with distinct landscape parameters (Schuster and Krizek 1978), thus

providing a basis for prediction of these processes in a spatial context. Random climatic factors can interact with landscape system variables. Given suitable conditions, strength thresholds for specific ecosites can be surpassed resulting in mass movement processes. Prediction of temporal frequencies is however very difficult due to the complexity of interactions that could occur. Mass movements may be naturally originating, anthropogenically induced or occur from a combination of these two influences.

2.3 Sediment Delivery Potential

Three general sediment delivery potentials can be recognized:

1. Ecosite disturbances
2. Riparian potential
3. Ecosite/riparian disturbance interactions

Ecosite disturbance potential can be related to three factors:

1. The ecosite properties
2. The disturbance type
3. The characteristics of the disturbance type pattern on the ecosite.

Ecosite disturbances represent an allocthonous sediment delivery potential deriving from interrelationships of the factors above.

Riparian sediment delivery potential derives from the interaction of stream flow regime energy with natural channel and stream bank materials. This type of potential is present in all streams and is often characterized by a dynamic equilibrium between discharge and load. Increases in flow regime may however disrupt equilibrium conditions resulting in changes to stream capacity and competence. Sediment concentration could thus be increased through varying conditions of accelerated channel scour, bank erosion and aggradation.

Ecosite/riparian disturbance interactions can occur when stream flow energy interacts with disturbances in the riparian zone. Sediment delivery potential in these cases is related to the combined factors governing the ecosite disturbance and riparian potentials.

3.0 METHODS

3.1 Ecosite Mapping and Classification

Review of existing biophysical data base information (Wells *et al.* 1972) was undertaken to provide familiarity with the study area. Ecosite delineations were then undertaken using 1:12 500 true colour aerial photography followed by field checking. Interpretations were stereoscopically transferred to scale corrected provincial inventory base maps. Map polygons were digitized and inputed to a mainframe version of the ArcInfo GIS.

Ecosite delineation and land sensitivity ratings followed the method of van Kesteren (1986).

Six levels of relative land sensitivity were recognized:

L_0 - none
L_1 - low
L_2 - moderate
L_3 - high
L_4 - very high
L_5 - extreme

Three parameters were utilized to derive the land sensitivity levels:

1. Relative soil erodibility - E
2. Slope class - S
3. Groundwater class - G

Appendices I, II, and III describe these parameters in greater detail.

Table 1 defines relative soil erodibility using pedologic and geomorphic conditions that can be recognized on aerial photographs.

Groundwater classes are as follows:

G_0 - no predominant groundwater influence in soil profile
G_1 - lateral seepage of soil water (interflow)
G_2 - perched or true groundwater influence in soil profile
$G_2(i)$ - Class G_2 with periodic inundation

The parameter subdivisions were combined as shown in Figure 3. Table 2 shows all the combinations and the corresponding sensitivity levels. The determination of the parameter combination provides the basis for interpretation and assignment of a particular sensitivity level to an ecosite.

The next step in developing the rating system was the synthesis of the various parameter combinations into groups. These groups consisted of ecosites characterized by similar ecological conditions. Thus, the ecosites comprising a group could be expected to react similarly to a particular form of disturbance and therefore specific mitigative guidelines could be applied. Table 3 shows the various ecosite groups and subgroups with a summary of related ecological conditions. Appendix IV presents more detail on the ecosite groups.

The land sensitivity ratings were derived by combining sensitivity levels and ecosite groups. The final rating defines the relative degree of sensitivity and details the predominant site conditions for a delineated ecosite polygon.

3.2 Water Yield Assessment

A simple provisional and conceptual water yield assessment was undertaken to address concerns of water supply. A conceptual approach, as indicated by Dooge (1984) and Shelton (1989), derives runoff modelling from an *a prior* recognition of physical processes that operate in a watershed. Milly and Eagleson (1987) indicate local variability of biological, pedological and geomorphological parameters as a major source of variation in hydrologic fluxes, with consequent difficulties in application of physical theory for hydrological response prediction at catchment scales. Additionally, Shelton (1989) indicates that subdivision of large watersheds into areal units reflecting spatial heterogeneities of physical process, as related to land surface parameters, can increase modelling accuracy. In the present study, ecosites as defined by Environment Canada (1981) and van Kesteren (1986) were mapped. This mapping provides a detailed subdivision of the Corner Brook Lake watershed into terrain units which have strong linkages to physical process.

Table 1. Relationship of relative soil erodibility to pedologic and geomorphic conditions.

Relative Erodibility	Particle Size Class[1] Field Texture[2]	(Symbol)	Genetic Category[3]	Probable Textural Classes and (Inclusions)
E_0 (none)	Consolidated bedrock			
	Unconsolidated rock			
	Blocky (angular, size > 256 mm)	(a)	Rock	Consolidated bedrock and unconsolidated rock; non soil:
	Bouldery (rounded, size > 256 mm)	(b)	Alluvial	unconsolidated mineral and/or organic materials < 10 cm
	Rubbly (angular, size > 2-256 mm)	(r)		in depth a, b, r, g
	Gravelly (rounded, size > 2-256 mm)	(g)		
E_1 (low)	Coarse sand	(cos)	Alluvial	cos, s, fs, vfs (g, b)
	Sand	(s)	Eolian	cos, s, fs, vfs
	Fine sand	(fs)	Glaciofluvial	cos, s, fs, vfs (g, b)
	Very fine sand	(vfs)	Morainal	cos, s, fs, vfs (r, a)
E_2 (moderate)	Loamy coarse sand	(lcos)	Alluvial	lcos, ls, lfs, lvfs (g, b)
	Loamy sand	(ls)	Glaciofluvial	lcos, ls, lfs, lvfs (g, b)
	Loamy fine sand	(lfs)	Morainal	lcos, ls, lfs, lvfs cosl, sl, fsl, vfsl (r, a)
	Loamy very fine sand	(lvfs)		
	Coarse sandy loam	(cosl)	Colluvial	lcos, ls, lfs, lvfs, cosl, sl, fsl, vfsl (r, a)
	Sandy loam	(sl)		
	Fine sandy loam	(fsl)	Organic	of
	Very fine sandy loam	(vfsl)		
	Organic	(o)		
	fibric	(of)		
E_3 (high)	Loam	(l)		
	Silt loam	(sil)		
	Silt	(si)	Morainal	l, sil, scl, fscl, vfscl, cl, sicl, sc, sic, c (r, a)
	Sandy clay loam	(scl)		
	Fine sandy clay loam	(fscl)	Colluvial	l, sil, scl, fscl, vfscl, cl, sicl, sc, sic, c (r, a)
	Very fine sandy clay loam	(vfscl)		
	Clay loam	(cl)	Alluvial	l, sil, si (g, b)
	Silty clay loam	(sicl)	Lacustrine	si, c (cos, s, fs, vfs)
	Sandy clay	(sc)	Marine	si, sc, sic, c, hc (cos, s, fs, vfs)
	Silty clay	(sic)	Eolian	l, sil, si
	Clay	(c)	Organic	om, oh
	Heavy clay	(hc)		
	Organic	(o)		
	mesic	(om)		
	humic	(oh)		

[1] C.S.S.C. 1978.
[2] Day 1983.

SOIL ERODIBILITY CLASS

SLOPE CLASS	E_0	E_1	E_2	E_3
S_0 (0 - 5%)	NONE	NONE	LOW	MODERATE
S_1 (6 - 15%)	NONE	LOW	LOW	MODERATE
S_2 (16 - 30%)	NONE	LOW	MODERATE	MODERATE
S_3 (31 - 45%)	NONE	MODERATE	MODERATE	HIGH
S_4 (46 - 60%)	NONE	HIGH	HIGH	HIGH
S_5 (> 60%)	NONE	VERY HIGH	VERY HIGH	VERY HIGH

SOIL ERODIBILITY CLASS + SLOPE CLASS

GROUNDWATER CLASS	NONE	LOW	MODERATE	HIGH	VERY HIGH
G_0	L_0	L_1	L_2	L_3	L_4
G_1	L_0 / L_1	L_2	L_3	L_4	L_5
G_2 (i)	L_0 / L_1(L_2)	L_2 / (L_3)	L_3 / (L_4)	L_4	L_5

Figure 3. Derivation of levels of sensitivity based on erodibility, slope and groundwater classes.

Table 2. **Combinations of parameters (E - relative erodibility, S - slope, G - groundwater) and corresponding land sensitivity levels (L).**

$E_0S_0G_0$	$E_0S_0G_1$*	$E_0S_0G_2$(i)	L_0	L_0	$L_0(L_2)$
$E_0S_1G_0$	$E_0S_1G_1$*	$E_0S_1G_2$(i)	L_0	L_0	$L_0(L_2)$
$E_0S_2G_0$	$E_0S_2G_1$*	$E_0S_2G_2$*	L_0	L_0	L_0
$E_0S_3G_0$	$E_0S_3G_1$*	$E_0S_3G_2$*	L_0	L_0	L_0
$E_0S_4G_0$	$E_0S_4G_1$*	$E_0S_4G_2$*	L_0	L_0	L_0
$E_0S_5G_0$	$E_0S_5G_1$*	$E_0S_5G_2$*	L_0	L_0	L_0
$E_1S_0G_0$	$E_1S_0G_1$	$E_1S_0G_2$(i)	L_0	L_1	$L_1(L_2)$
$E_1S_1G_0$	$E_1S_1G_1$	$E_1S_1G_2$(i)	L_1	L_2	$L_2(L_3)$
$E_1S_2G_0$	$E_1S_2G_1$	$E_1S_2G_2$*	L_1	L_2	L_2
$E_1S_3G_0$	$E_1S_3G_1$	$E_1S_3G_2$*	L_2	L_3	L_3
$E_1S_4G_0$	$E_1S_4G_1$	$E_1S_4G_2$*	L_3	L_4	L_4
$E_1S_5G_0$	$E_1S_5G_1$	$E_1S_5G_2$*	L_4	L_5	L_5
$E_2S_0G_0$	$E_2S_0G_1$	$E_2S_0G_2$(i)	L_1	L_2	$L_2(L_3)$
$E_2S_1G_0$	$E_2S_1G_1$	$E_2S_1G_2$(i)	L_1	L_2	$L_2(L_3)$
$E_2S_2G_0$	$E_2S_2G_1$	$E_2S_2G_2$*	L_2	L_3	L_3
$E_2S_3G_0$	$E_2S_3G_1$	$E_2S_3G_2$*	L_2	L_3	L_3
$E_2S_4G_0$	$E_2S_4G_1$	$E_2S_4G_2$*	L_3	L_4	L_4
$E_2S_5G_0$	$E_2S_5G_1$	$E_2S_5G_2$*	L_4	L_5	L_5
$E_3S_0G_0$	$E_3S_0G_1$	$E_3S_0G_2$(i)	L_2	L_3	$L_3(L_4)$
$E_3S_1G_0$	$E_3S_1G_1$	$E_3S_1G_2$(i)	L_2	L_3	$L_3(L_4)$
$E_3S_2G_0$	$E_3S_2G_1$	$E_3S_2G_2$*	L_2	L_3	L_3
$E_3S_3G_0$	$E_3S_3G_1$	$E_3S_3G_2$*	L_3	L_4	L_4
$E_3S_4G_0$	$E_3S_4G_1$	$E_3S_4G_2$*	L_3	L_4	L_4
$E_3S_5G_0$	$E_3S_5G_1$	$E_3S_5G_2$*	L_4	L_5	L_5

* Occurrence of these combinations infrequent or improbable under natural conditions.

Table 3. Ecosite groups defined by all combinations of relative erodibility, slope and groundwater.

Ecosite Groups and Subgroups	Parameter Combinations and Related Sensitivity	Summary of Ecological Conditions
a, a(m)	$E_0S_0G_0$, $E_0S_0G_1$*, $E_0S_0G_2$* $E_0S_1G_0$, $E_0S_1G_1$*, $E_0S_1G_2$* $E_0S_2G_0$, $E_0S_2G_1$*, $E_0S_2G_2$* $E_0S_3G_0$, $E_0S_3G_1$*, $E_0S_3G_2$* $E_0S_4G_0$, $E_0S_4G_1$*, $E_0S_4G_2$* $E_0S_5G_0$, $E_0S_5G_1$*, $E_0S_5G_2$* (L_0)	Exposed bedrock or bedrock with < 10 cm cover of organic or mineral material; all slope classes and morphological types included. Subgroup (m), unstable rock subject to mass wasting.
b	$E_1S_0G_0$, $E_1S_1G_0$, $E_2S_0G_0$ $E_2S_1G_0$, $E_3S_0G_0$, $E_3S_1G_0$ (L_0, L_1, L_2)	Negligible to low, short, simple and complex slopes; groundwater not present within the soil profile; very rapidly to moderately well-drained; genetic materials predominately morainal or glaciofluvial.
c, c(o), c(l)	$E_0S_0G_2$(i), $E_0S_1G_2$(i) $E_1S_0G_2$(i), $E_1S_1G_2$(i) $E_2S_0G_2$(i), $E_2S_1G_2$(i) $E_3S_0G_2$(i), $E_3S_1G_2$(i) (L_1, L_2, L_3, L_4)	Negligible to low slopes with perched soil water or true groundwater; subject to periodic inundation; imperfectly to very poorly drained; variety of soil textures and parent materials. Subgroup c(o), organic soils; subgroup c(l), alluvial mineral soils.
d, d(o), d/d(o)	$E_1S_0G_1$, $E_1S_1G_1$, $E_1S_2G_1$ $E_1S_3G_1$, $E_1S_4G_1$, $E_1S_5G_1$ $E_2S_0G_1$, $E_2S_1G_1$, $E_2S_2G_1$ $E_2S_3G_1$, $E_2S_4G_1$, $E_2S_5G_1$ $E_3S_0G_1$, $E_3S_1G_1$, $E_3S_2G_1$ $E_3S_3G_1$, $E_3S_4G_1$, $E_3S_5G_1$ (L_1, L_2, L_3, L_4, L_5)	Slopes that promote subsurface seepage of soil water; genetic materials primarily morainal and/or colluvial; seepage dominant in lower slope positions and less prominent in middle and upper slope positions. Subgroup d(o), organic soils; subgroup d/d(o), organic and mineral soils.
e	$E_1S_2G_0$, $E_1S_3G_0$, $E_1S_4G_0$ $E_1S_5G_0$, $E_2S_2G_0$, $E_2S_3G_0$ $E_2S_4G_0$, $E_2S_5G_0$, $E_3S_2G_0$ $E_3S_3G_0$, $E_3S_4G_0$, $E_3S_5G_0$ (L_1, L_2, L_3, L_4)	Short, moderate to steep, simple and complex slopes; little or no prominent subsurface seepage due to moderately well-drained to rapidly drained condition of slope.
f*	$E_1S_2G_2$, $E_1S_3G_2$, $E_1S_4G_2$ $E_1S_5G_2$, $E_2S_2G_2$, $E_2S_3G_2$ $E_2S_4G_2$, $E_2S_5G_2$, $E_3S_2G_2$ $E_3S_3G_2$, $E_3S_4G_2$, $E_3S_5G_2$ (L_2, L_3, L_4, L_5)	Moderate to steep slopes; perched soil water.

* Occurrence of these combinations infrequent or improbable under natural conditions.

Two parameters used to map the ecosites were soil textural class as inferred from genetic category and slope gradient. Using these parameters, ecosites were ranked for potential hydrologic response. These rankings were assumed to reflect a deterministic interaction of climatic inputs with the land surface parameters. Implicit in this assumption is that short term spatio-temporal lag factors are trended towards an average condition resulting in a predictable maintenance of long term water yield partitioning. On this basis, the ecosite types were considered to be discrete locationally independent land response units for water yield.

The rankings were derived through a calculation of an approximate, steady state specific discharge for the ecosites. This calculation was achieved through an application of Darcy's law:

$$v = -K \frac{dh}{dl}$$ *(Freeze and Cherry 1979, Bedient and Huber 1989)*

where v = specific discharge (Darcy flux)
K = saturated hydraulic conductivity

$\frac{dh}{dl}$ = *hydraulic gradient*

Values for K were assigned to the soil textural classes (Table 1) as follows:

Class	K (cm/sec)
E_0	1 x 10^{1} (McCarthy 1988)
E_1	1 x 10^{0} (McCarthy 1988)
E_2	1.8 x 10^{-1} (Chow & Roberts 1985)
E_3	1 x 10^{-3} (McCarthy 1988)
E_2 (fibric peat)	5.58 x 10^{-4} (MacFarlane 1969)
E_3 (mesic peat)	0.75 x 10^{-5} (MacFarlane 1969)

Hydraulic gradient values were derived from the median of the slope classes in Appendix 2 as follows:

Class	$\frac{dh}{dl}$
S_0(0-5%)	0.025
S_1(6-15%)	0.105
S_2(16-30%)	0.230
S_3(31-45%)	0.380
S_4(46-60%)	0.530
S_5(>60%)	0.680

Calculated values of v for the mapped ecosites were ranked with the maximum value assigned as 100 and remaining values being ranked as a percentage of the maximum. Water yield ranks are presented in sections 4.1 and 4.3.

Application of the rankings to an area summary, assuming a predominant steady state interflow process, enabled an approximation of the relative annual percentage contribution to water yield generated by the ecosite types.

Many case studies have demonstrated increased water yields resulting from timber harvest. Through assignment of a percentage increase factor and proceeding under an assumption that an overall increase will partition proportionately to the ecosite rankings, potential increases may be assessed for timber harvest on differing ecosite types.

Water yield computations on a relative annual percentage basis for specific ecosite types utilize the following variables:

A = Total area for a specific ecosite type.

Ac = Total area proposed for harvest in a specific ecosite type.

χ = Water yield rank for a specific ecosite type.

χ^1 = Maximum water yield rank of the inventoried ecosites.

A^1 = A, converted to an equivalent rank χ^1 area.

Σ_A^1 = Total converted area of all inventoried ecosites.

% W.Y. = Relative percentage water yield by ecosite type.

% W.Y.(a) = Relative percentage water yield per unit area by ecosite type.

% $W.^1Y.^1$ = Relative percentage water yield increase by ecosite type due to timber harvest.

P = Percentage factor for water yield increases due to timber harvest. Determination of an appropriate value of P may present difficulties. For small experimental watersheds case studies have demonstrated that percentage water yield increases can be very high when the full area is harvested over a short time. In large operational watersheds subject to smaller cuts spread over a longer time, high percentage water yield increases in low order streams may be attenuated, thus resulting in lower percentage water yield increases in higher order streams. Bosch and Hewlett (1982) indicate that harvesting 20% or less of a catchment may result in no detectable water yield increases. In this study, P values in the range of 0.0 - 5.0% were considered to be acceptable for the full watershed or large subcatchments.

Computational formulae are as follows:

1. $$A^1 = \frac{\chi}{\chi^1} A$$

2. $$\%\ W.Y. = \frac{A^1}{\Sigma_A^1}\ X\ 100\%$$

3. $$\%\ W.Y.(a) = \frac{\%\ W.Y.}{A}$$

4. $$\%\ W.^1Y.^1 = \%\ W.Y.(a)\ X\ Ac\ X\ P$$

The water yield assessment can be applied on two levels:

1. The catchment level
2. A subcatchment level

Within a catchment, subcatchments of lower basin order may be delineated through recognition of topographic divides and the presence of ordered stream networks. Runoff from these subcatchments, through lower order streams, contribute to the total watershed discharge.

4.0 RESULTS

4.1 Ecosite Inventory

Twenty-four recurring ecosites have been mapped in the Corner Brook Lake watershed. An inventory summary is presented in Table 4. Some 9013.83 ha of land have been classified by land sensitivity ratings. Approximately 511 ha are classified in the types $L_{4c(l)}$, $L_{4c(o)}$, L_{5d} and $L_{5d/d(o)}$. These types are considered to be sensitive enough to be excluded from harvest operations. This represents a 5.67% exclusion from the watershed landbase.

Potential severity of disturbances resulting from harvesting are indicated in Table 5. These potentials assume comparison of similar disturbance types and intensities by ecosite type. Figure 4 depicts a generalized profile of topographic and relief relationships. Descriptive summaries of the ecosites which follow represent the average field condition.

Ecosite: L_{oa}
Soils/Geomorphology: Primarily exposed bedrock surfaces. Some inclusions of thin fibric organic and mineral soils of coarse gravelly texture can occur.
Slope/Topography (Fig. 4): Slopes ranging from 0%-61% with a variable topography. Generally high elevation summit sites, although atypical lower elevation sites can occur.
Soil Water/Groundwater: An absence of soil water with site drainage by means of rapid to very rapid surface runoff and shallow discontinuous subsurface flow.
Total Area (ha): 1375.84
Number of Polygons: 599
Mean Polygon Area (ha): 2.30
Water Yield Rank: 37.30

Ecosite: $L_{oa(m)}$
Soils/Geomorphology: Primarily exposed bedrock surfaces including unconsolidated talus deposits of bedrock rubble. Sites can have active natural landslide occurrences.
Slope/Topography (Fig. 4): Slopes ranging from 61% and greater with generally straight or concave simple slopes. Primarily high elevation sites.
Soil Water/Groundwater: An absence of soil water with site drainage by means of rapid to very rapid surface runoff and shallow discontinuous subsurface flow.
Total Area (ha): 33.50
Number of Polygons: 18
Mean Polygon Area (ha): 1.86
Water Yield Rank: 100.00

Ecosite: L_{1b}
Soils/Geomorphology: Primarily glacial till deposits of variable depth. Soils are generally orthic podzols. Minor inclusions of gleyed podzols and gleysols will occur. Textures primarily moderately coarse to coarse.
Slope/Topography (Fig. 4): Slopes ranging from 0%-15% with flat to rolling topography. Generally lower elevation sites.
Soil Water/Groundwater: Groundwater table is generally below the taxonomic profile. Site drainage ranges from moderately well to rapidly drained.
Total Area (ha): 93.80
Number of Polygons: 47
Mean Polygon Area (ha): 2.00
Water Yield Rank: 0.18

Ecosite: L_{1c}
Soils/Geomorphology: Primarily thin coarse gravelly soils and thin organic soils developed *in situ*, occurring in conjunction with L_{oa} sites.

Table 4. Ecosite inventory summary.

Ecosite Type	Total Area (ha)	Number of Polygons	Mean Area (ha)	Sensitivity Level
L_{oa}	1375.84	599	2.30	none
$L_{oa(m)}$	33.50	18	1.86	none
L_{1b}	93.80	47	2.00	low
L_{1c}	19.66	37	0.53	low
L_{2b}	232.58	91	2.56	moderate
L_{2c}	692.30	144	4.81	moderate
$L_{2c(o)}$	144.59	233	0.62	moderate
L_{2d}	312.73	135	2.32	moderate
$L_{2d/d(o)}$	128.51	72	1.78	moderate
L_{2e}	1331.35	477	2.79	moderate
$L_{3c(o)}$	589.77	704	0.84	high
$L_{3c(l)}$	11.17	24	0.47	high
L_{3d}	1809.08	254	7.12	high
$L_{3d(o)}$	246.31	137	1.80	high
$L_{3d/d(o)}$	777.29	304	2.56	high
L_{3e}	111.54	36	3.10	high
$L_{4c(o)}$	50.91	83	0.61	very high
$L_{4c(l)}$	10.61	17	0.62	very high
L_{4d}	366.42	73	5.02	very high
$L_{4d(o)}$	16.36	10	1.64	very high
$L_{4d/d(o)}$	58.94	43	1.37	very high
L_{4e}	150.95	39	3.87	very high
L_{5d}	334.07	39	8.57	extreme
$L_{5d/d(o)}$	115.55	58	1.99	extreme

Table 5. Potential severity of ecosite disturbances.

Disturbance	Ecosite Types												
	L_{oa}	$L_{oa(m)}$	L_{1b}	L_{1c}	L_{2b}	L_{2c}	$L_{2c(o)}$	L_{2d}	$L_{2d/d(o)}$	L_{2e}	$L_{3c(o)}$	$L_{3c(l)}$	L_{3d}
Soil Compaction	0	0	2	1	4	1	1	1	1	3	2	1	2
Soil Deformation	0	0	1	2	1	3	3	3	3	1	5	4	2
Water Impoundment	0	0	0	0	1	3	2	2	2	1	4	3	2
Sheet Erosion	1	1	0	0	1	0	0	1	1	2	0	0	3
Channelized Erosion	0	0	0	0	1	0	0	1	1	1	0	0	3
Landslides	-	-	-	-	-	-	-	-	-	-	-	-	-
Type A	0	5*	0	0	0	0	0	0	0	0	0	0	0
Type B	0	0	0	0	0	0	0	0	0	0	0	0	0
Type C	0	0	0	0	0	0	0	0	0	0	0	0	0
Sediment Delivery	-	-	-	-	-	-	-	-	-	-	-	-	-
Ecosite Disturbance	0	0	0	0	1	1	1	2	1	1	1	3	3
Riparian Potential	0	0	1	1	1	2	2	1	1	1	4	4	2
Ecosite/Riparian Disturbance Interactions	1	1	1	1	2	2	3	2	2	2	4	5	3

... (Cont'd.)

Table 5. (Concl'd.)

Disturbance	Ecosite Types											
	L_{3d}	$L_{3d(o)}$	$L_{3d/d(o)}$	L_{3e}	$L_{4c(o)}$	$L_{4c(1)}$	L_{4d}	$L_{4d(o)}$	$L_{4d/d(o)}$	L_{4e}	L_{5d}	$L_{5d/d(o)}$
Soil Compaction	2	2	2	2	3	2	2	2	2	2	2	2
Soil Deformation	2	4	3	3	5	4	3	5	4	4	4	5
Water Impoundment	2	3	3	1	5	5	1	3	2	1	1	1
Sheet Erosion	3	1	2	3	0	0	4	2	3	4	5	5
Channelized Erosion	3	2	3	3	0	0	4	4	4	3	5	5
Landslides	-	-	-	-	-	-	-	-	-	-	-	-
Type A	0	0	0	0	0	0	(4)	(2)	(4)	(4)	(5)	(5)
Type B	0	0	0	0	0	0	(4)	(3)	(4)	(4)	(5)	(5)
Type C	0	0	0	0	0	0	(4)	(2)	(4)	(4)	(5)	(5)
Sediment Delivery	-	-	-	-	-	-	-	-	-	-	-	-
Ecosite Disturbance	3	2	2	3	2	4	4	3	3	4	5	4
Riparian Potential	2	3	2	2	5	5	3	4	3	3	4	4
Ecosite/Riparian Disturbance Interactions	3	3	3	3	5	5	4	4	4	4	5	5

Severity Levels:

0...negligible
1...low
2...moderate
3...high
4...very high
5...extreme
*...primarily natural occurrences.
( )...Occurrences natural or induced through site disturbance.

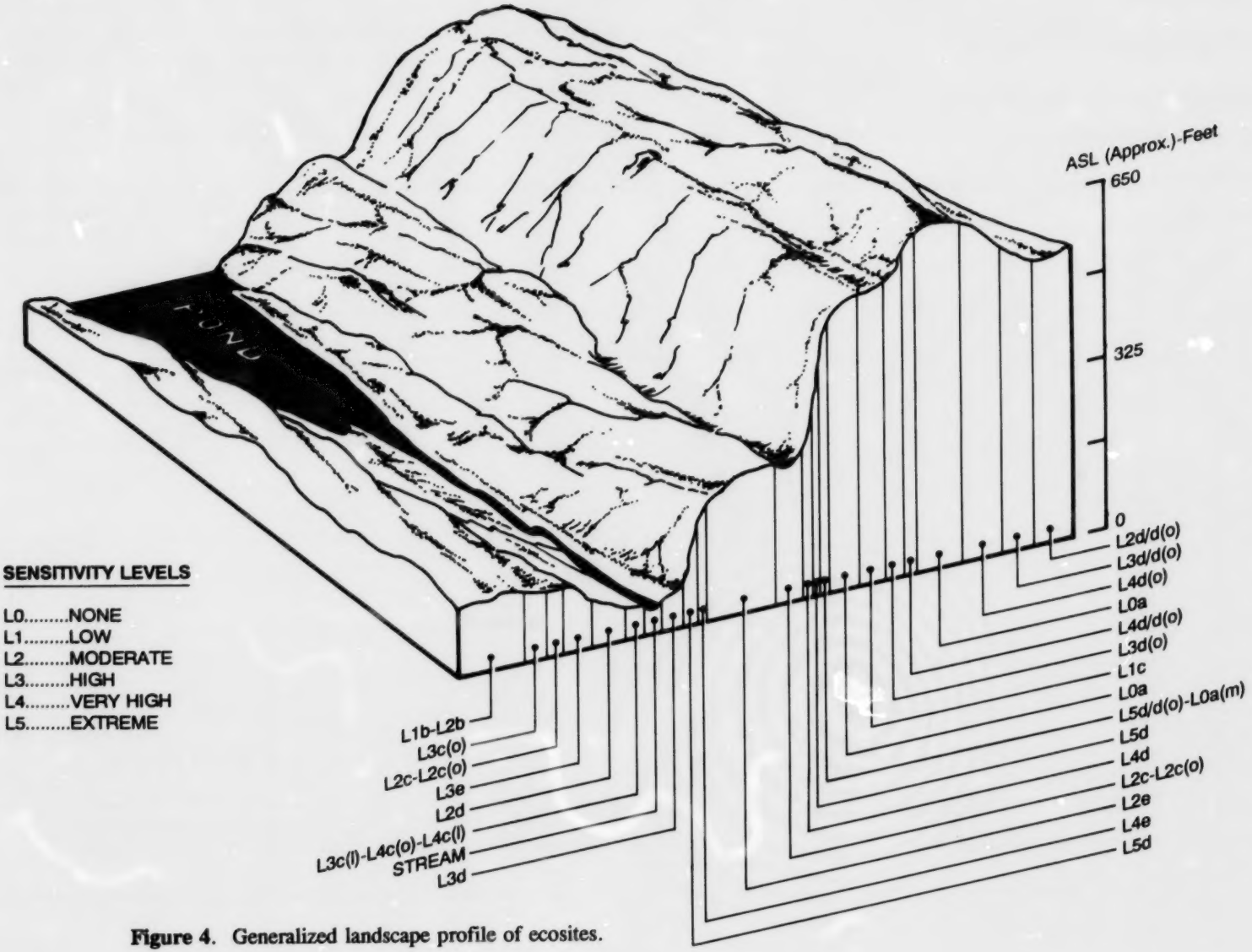


Figure 4. Generalized landscape profile of ecosites.

Slope/Topography (Fig. 4): Slopes ranging from 0%-15% with basin topography which restricts drainage. Generally high elevation sites.
Soil Water/Groundwater: Generally perched soil water with imperfect to very poorly drained conditions.
Total Area (ha): 19.66
Number of Polygons: 37
Mean Polygon Area (ha): 0.53
Water Yield Rank: 0.96

Ecosite: L_{2b}
Soils/Geomorphology: Primarily fine to moderately fine textured soils; silt loams and loams derived from glacial till deposits; generally orthic podzols and inclusions of gleyed podzols.
Slope/Topography (Fig. 4): Slopes ranging from 0%-15% with flat to rolling topography. Generally lower elevation sites.
Soil Water/Groundwater: Groundwater table is generally below the taxonomic profile. Site drainage ranges from moderately well to well drained.
Total Area (ha): 232.58
Number of Polygons: 91
Mean Polygon Area (ha): 2.56
Water Yield Rank: 0.0026

Ecosite: L_{2c}
Soils/Geomorphology: Primarily moderately coarse to fine textured mineral soils often overlain by fibric and mesic peat soils of variable depth.
Slope/Topography (Fig. 4): Slopes ranging from 0%-15% with basin topography which restricts drainage. Generally lower to mid elevation sites.
Soil Water/Groundwater: Generally perched soil water with imperfect to very poorly drained conditions.
Total Area (ha): 692.30
Number of Polygons: 144
Mean Polygon Area (ha): 4.81
Water Yield Rank: 0.18

Ecosite $L_{2c(o)}$
Soils/Geomorphology: Primarily deep organic soils with fibric peat dominant.
Slope/Topography (Fig. 4): Slopes ranging from 0%-15% with the peat often developed in topographic basins which restrict drainage. Primarily mid to high elevation sites.
Soil Water/Groundwater: Generally perched soil water with poor to very poorly drained conditions.
Total Area (ha): 144.59
Number of Polygons: 233
Mean Polygon Area (ha): 0.62
Water Yield Rank: 0.0005

Ecosite: L_{2d}
Soils/Geomorphology: Glacial till deposits with soil textures generally from moderately coarse to fine. Gleysols and gleyed podzols are the dominant soil types. Discontinuous areas of shallow peat may overlay mineral soils.
Slope/Topography (Fig. 4): Slopes ranging from 0%-15% with generally simple concave slopes. Primarily low elevation sites.
Soil Water/Groundwater: Primarily slow lateral seepage of soil water resulting in imperfect to poorly drained conditions.
Total Area (ha): 312.73
Number of Polygons: 135
Mean Polygon Area (ha): 2.32
Water Yield Rank: 0.28

Ecosite: $L_{2d/d(o)}$
Soils/Geomorphology: Primarily glacial till deposits with thin coarse to moderately coarse soil textures. Mineral soils are complexed with thin organic soils. Soil types would be primarily gleyed regosols and rego gleysols.

Slope/Topography (Fig. 4): Slopes ranging from 0%-15% with generally simple concave slope profiles. Primarily high to mid elevation sites.
Soil Water/Groundwater: Primarily slow lateral seepage of soil water resulting in imperfect to poorly drained conditions.
Total Area (ha): 128.51
Number of Polygons: 72
Mean Polygon Area (ha): 1.78
Water Yield Rank: 2.46

Ecosite: L_{2c}
Soils/Geomorphology: Primarily glacial till deposits of variable texture. Soils are generally orthic podzols and gleyed podzols. Higher elevation sites may have coarse to moderately coarse thin soils, whereas lower elevation sites can have deeper soils with moderately coarse to fine textures.
Slope/Topography (Fig. 4): Slopes ranging from 16%-45%. Complex slope patterns with short side slopes and summits. These sites extend from low to high elevations.
Soil Water/Groundwater: Sites are generally moderately well to rapidly drained. Higher elevation sites may be moister than lower elevation sites. Lateral seepage of soil water can occur for short periods of time on side slopes.
Total Area (ha): 1331.35
Number of Polygons: 477
Mean Polygon Area (ha): 2.79
Water Yield Rank: 0.44

Ecosite: $L_{3c(o)}$
Soils/Geomorphology: Organic deposits with primarily mesic and humic soils. Depth can be variable but generally less than 3 metres.
Slope/Topography (Fig. 4): Slopes ranging from 0%-15% with the type occurring through low to high elevations.
Soil Water/Groundwater: Primarily perched soil water with poor to very poor drainage.
Total Area (ha): 589.77
Number of Polygons: 704
Mean Polygon Area (ha): 0.84
Water Yield Rank: 0.000007

Ecosite: $L_{3c(l)}$
Soils/Geomorphology: Primarily fluvial sediments deposited along stream courses. Soils can be complex with polymodal particle size distribution (e.g. gravels, sands, and humus mixes).
Slope/Topography (Fig. 4): Slopes generally ranging from 0%-15% in association with low gradient stream reaches.
Soil Water/Groundwater: Sites are subject to periodic inundation and rise of groundwater in soil profiles. Drainage is imperfect to very poor.
Total Area (ha): 11.17
Number of Polygons: 24
Mean Polygon Area (ha): 0.47
Water Yield Rank: 0.07

Ecosite: L_{3d}
Soils/Geomorphology: Primarily glacial till and colluvial deposits with moderately coarse to fine textured soils. A surface rubble of boulder colluvium may be encountered in the type. Soil types primarily gleyed podzols and gleysols.
Slope/Topography (Fig. 4): Simple long slopes with generally concave profiles ranging from 16%-45%.
Soil Water/Groundwater: Lateral seepage of soil water is predominant and generally present throughout the growing season. Moderately well to imperfect drainage conditions prevail. An increased frequency of intermittent and ephemeral drainages are often associated with this type.
Total Area (ha): 1809.08

Number of Polygons: 254
Mean Polygon Area (ha): 7.12
Water Yield Rank: 0.54

Ecosite: $L_{3d(o)}$
Soils/Geomorphology: Shallow organic soils generally less than 2 metres in depth with primarily mesic and fibric peat.
Slope/Topography (Fig. 4): Slopes ranging from 16%-45% with generally simple long slopes with concave profiles.
Soil Water/Groundwater: Lateral seepage of soil water is predominant with imperfect to very poor drainage conditions.
Total Area (ha): 246.31
Number of Polygons: 137
Mean Polygon Area (ha): 1.80
Water Yield Rank: 0.000019

Ecosite: $L_{3d/d(o)}$
Soils/Geomorphology: Primarily glacial till deposits with thin coarse to moderately coarse soil textures. Mineral soils may be complexed with thin fibric and mesic organic soils. Mineral soil types would be primarily gleyed regosols and rego gleysols.
Slope/Topography (Fig. 4): Slopes ranging from 16%-45% with generally simple concave slope profiles. Primarily mid to high elevation sites.
Soil Water/Groundwater: Predominantly lateral seepage of soil water resulting in moderately well to imperfectly drained conditions.
Total Area (ha): 777.29
Number of Polygons: 304
Mean Polygon Area (ha): 2.56
Water Yield Rank: 5.59

Ecosite: L_{3e}
Soils/Geomorphology: Primarily glacial tills of moderately coarse to fine textures; soil types orthic podzols with minor inclusions of gleyed podzols.
Slope/Topography (Fig. 4): Generally short simple straight to convex slope profiles with gradients ranging from 31%-60%.
Soil Water/Groundwater: Moderately well to rapidly drained sites with little or no predominant seepage of soil water.
Total Area (ha): 111.54
Number of Polygons: 36
Mean Polygon Area (ha): 3.10
Water Yield Rank: 0.81

Ecosite: $L_{4c(o)}$
Soils/Geomorphology: Organic deposits with mesic and humic peat soils; depth can be variable but is generally shallow < 1 metre.
Slope/Topography (Fig. 4): Slopes ranging from 0%-15%. This type generally occurs along stream courses and stream outlets into standing water.
Soil Water/Groundwater: Subject to significant fluctuations in water level from flooding and seasonal peaks in discharge.
Total Area (ha): 50.91
Number of Polygons: 83
Mean Polygon Area (ha): 0.61
Water Yield Rank: 0.000003

Ecosite: $L_{4c(l)}$
Soils/Geomorphology: Primarily fluvial sediments deposited along stream courses. Soils can be complex with polymodal particle size distribution (e.g. gravels, sands, silts and humus mixes).
Slope/Topography (Fig. 4): Slopes generally ranging from 0%-15% occurring in association with low gradient stream reaches.
Soil Water/Groundwater: Sites are subject to periodic inundation and rise of groundwater in soil profiles. Drainage is imperfect to very poor.

Total Area (ha): 10.61
Number of Polygons: 17
Mean Polygon Area (ha): 0.62
Water Yield Rank: 0.00037

Ecosite: L_{4d}
Soils/Geomorphology: Primarily glacial till and colluvial deposits with moderately coarse to fine textured soils. A surface rubble of boulder colluvium can be encountered in the type. Soil types primarily gleyed podzols and gleysols.
Slope/Topography (Fig. 4): Simple long slopes with generally concave and straight slope profiles ranging from 46%-60%.
Soil Water/Groundwater: Lateral seepage of soil water is predominant and generally present throughout the growing season. Moderately well to imperfect drainage conditions prevail. An increased frequency of intermittent and ephemeral drainages are often associated with this type.
Total Area (ha): 366.42
Number of Polygons: 73
Mean Polygon Area (ha): 5.02
Water Yield Rank: 1.40

Ecosite: $L_{4d(o)}$
Soils/Geomorphology: Shallow organic deposits less than 2 metres in depth with primarily mesic and humic peat.
Slope/Topography (Fig. 4): Slopes ranging from 46%-60% with generally simple long slopes with concave profiles.
Soil Water/Groundwater: Lateral seepage of soil water is predominant with imperfect to very poor drainage conditions.
Total Area (ha): 16.36
Number of Polygons: 10
Mean Polygon Area (ha): 1.64
Water Yield Rank: 0.00005

Ecosite: $L_{4d/d(o)}$
Soils/Geomorphology: Primarily glacial till and colluvial deposits with thin coarse to moderately coarse soil textures. Mineral soils may be complexed with thin fibric and mesic organic soils. Mineral soil types would be primarily gleyed regosols and rego gleysols.
Slope/Topography (Fig. 4): Slopes ranging from 46%-60% with generally simple concave and straight slope profiles. Primarily high to mid elevation sites.
Soil Water/Groundwater: Primarily lateral seepage of soil water with well to rapidly drained conditions.
Total Area (ha): 58.94
Number of Polygons: 43
Mean Polygon Area (ha): 1.37
Water Yield Rank: 7.79

Ecosite: L_{4e}
Soils/Geomorphology: Primarily glacial tills and colluvial deposits of moderately coarse to coarse textures; soil types orthic podzols with minor inclusions of gleyed podzols and folisols.
Slope/Topography (Fig. 4): Generally short simple straight to convex slope profiles with gradients ranging from 61% and steeper.
Soil Water/Groundwater: Moderately well to very rapidly drained sites with little or no predominant seepage of soil water.
Total Area (ha): 150.95
Number of Polygons: 39
Mean Polygon Area (ha): 3.87
Water Yield Rank: 5.90

Ecosite: L_{5d}
Soils/Geomorphology: Primarily shallow glacial till and colluvial deposits with moderately coarse to fine textured soils. A surface rubble of boulder colluvium can be

encountered in the type. Soil types primarily gleyed podzols and gleysols.
Slope/Topography (Fig. 4): Simple long slopes with generally concave and straight slope profiles ranging from 61% and steeper.
Soil Water/Groundwater: Lateral seepage of soil water is predominant and generally present throughout the growing season. Moderately well to imperfect drainage conditions prevail. An increased frequency of intermittent and ephemeral drainages are often associated with this type.
Total Area (ha): 334.07
Number of Polygons: 39
Mean Polygon Area (ha): 8.57
Water Yield Rank: 3.93

Ecosite: $L_{3d/d(o)}$
Soils/Geomorphology: Primarily shallow glacial till and colluvial deposits with coarse to moderately coarse soil textures. Mineral soils are complexed with thin fibric and mesic organic soils. Mineral soil types would be primarily gleyed regosols and rego gleysols.
Slope/Topography (Fig. 4): Slopes ranging from 61% and steeper with generally simple concave and straight slope profiles. Primarily high to mid elevation sites.
Soil Water/Groundwater: Primarily lateral seepage of soil water resulting in rapid to very rapidly drained conditions.
Total Area (ha): 115.55
Number of Polygons: 58
Mean Polygon Area (ha): 1.99
Water Yield Rank: 10.0

4.2 Mass Movements

Three general mass movement types may occur in the Corner Brook Lake watershed. These are depicted in Figures 5, 6, 7. Explanations of ecosite terminology are contained in Section 4.1, Appendices I to IV and van Kesteren (1986).

Type A mass movements can occur where metamorphic and igneous lithologies combine with suitable catenary conditions. These rock types are common in the watershed (Hibbard 1985). Jointing and massive blocky structure is characteristic resulting in the potential for structural failure. Overland and subsurface flow from summits can contribute to freeze-thaw processes, thereby accelerating structural failure through joint exploitation and headward erosion. Additionally, shallow rooted tree growth on upper slope ecosites could contribute to structural weakening of bedrock through mechanical and chemical weathering influences.

Figure 5 presents a typical catenary sequence of ecosites which could be subject to mass movements of type A. The ecosite $L_{oa(m)}$ is at some initial time stable, but may be subject to failure with subsequent parallel slope retreat. Boulder colluvium in the adjoining ecosites L_{4d} and L_{3d} is indicative of former mass movement activity. However, it is important to note that rates and processes of past "landslide" occurrences may have been significantly different due to late glacial and periglacial conditions. Mass movements of type A may incorporate soil and vegetation materials, creating visible "landslide" scars in adjoining ecosites. The "landslide" energy will be generally dissipated as a function of decreasing slope gradient and increasing distance from the point of origin.

Type B mass movements (Figure 6) may occur where sedimentary lithologies and metamorphosed equivalents combine with suitable catenary conditions. Steeply

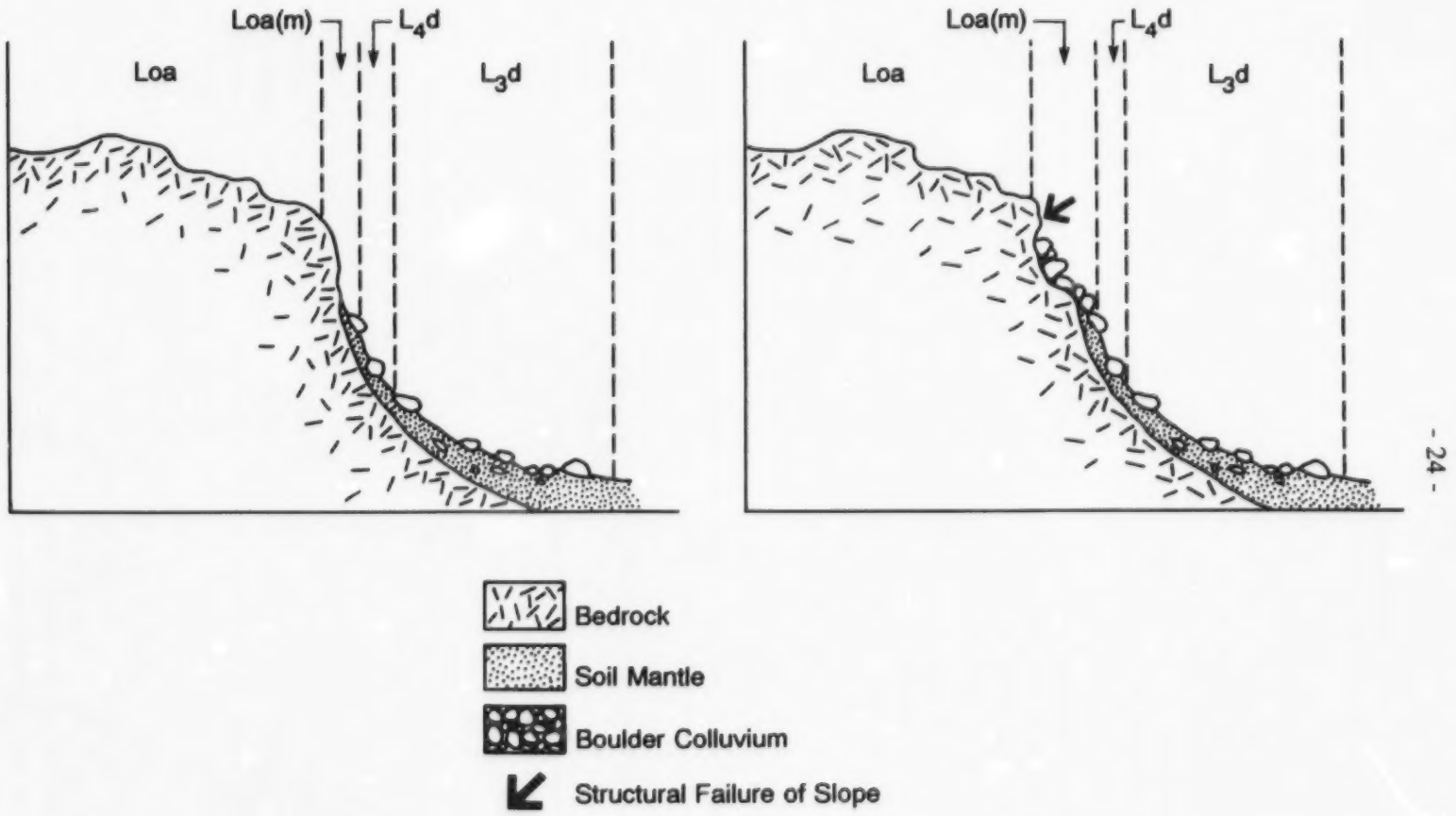


Figure 5. Mass Movement - Type A.

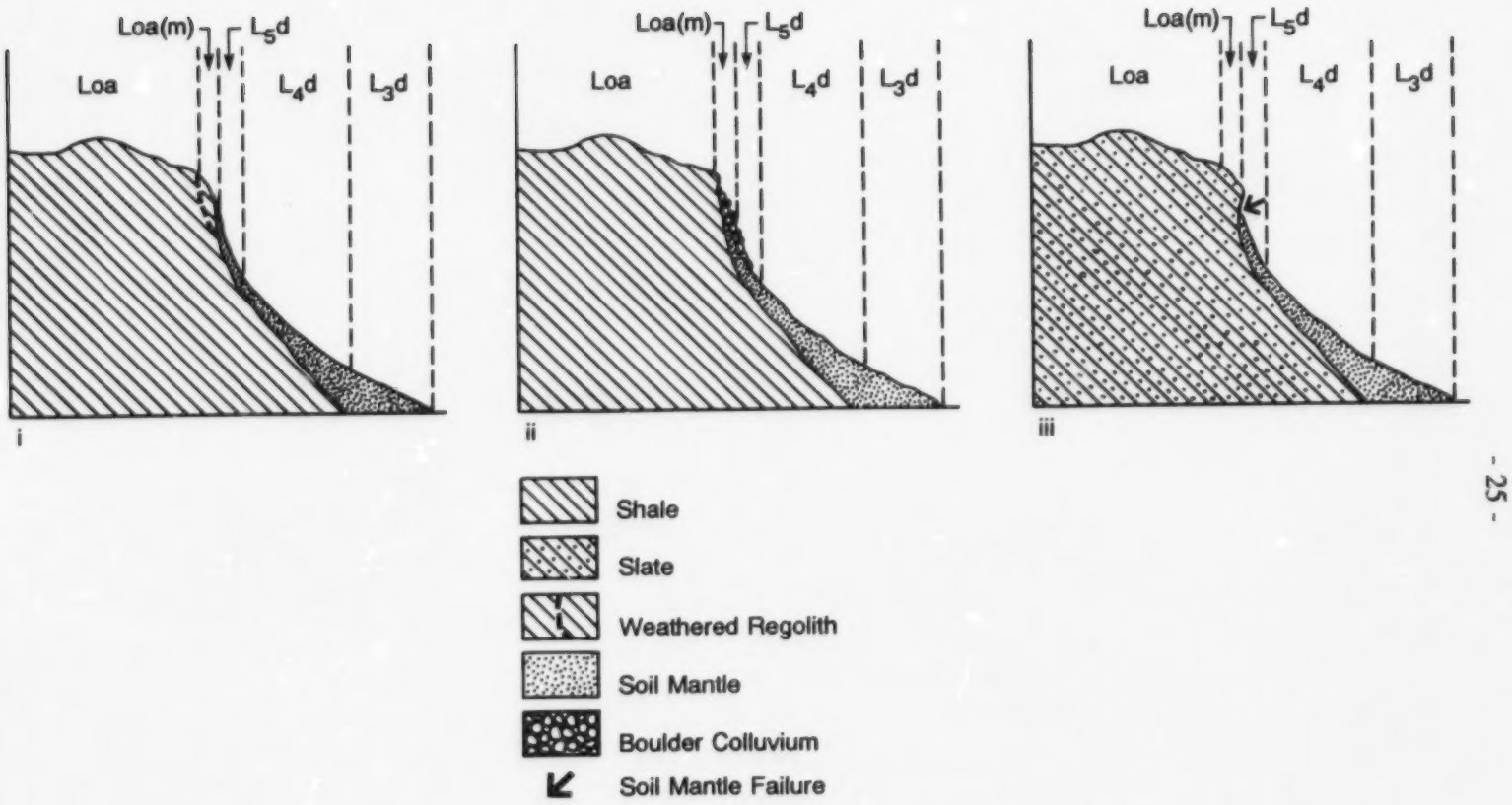


Figure 6. Mass movement - Type B.

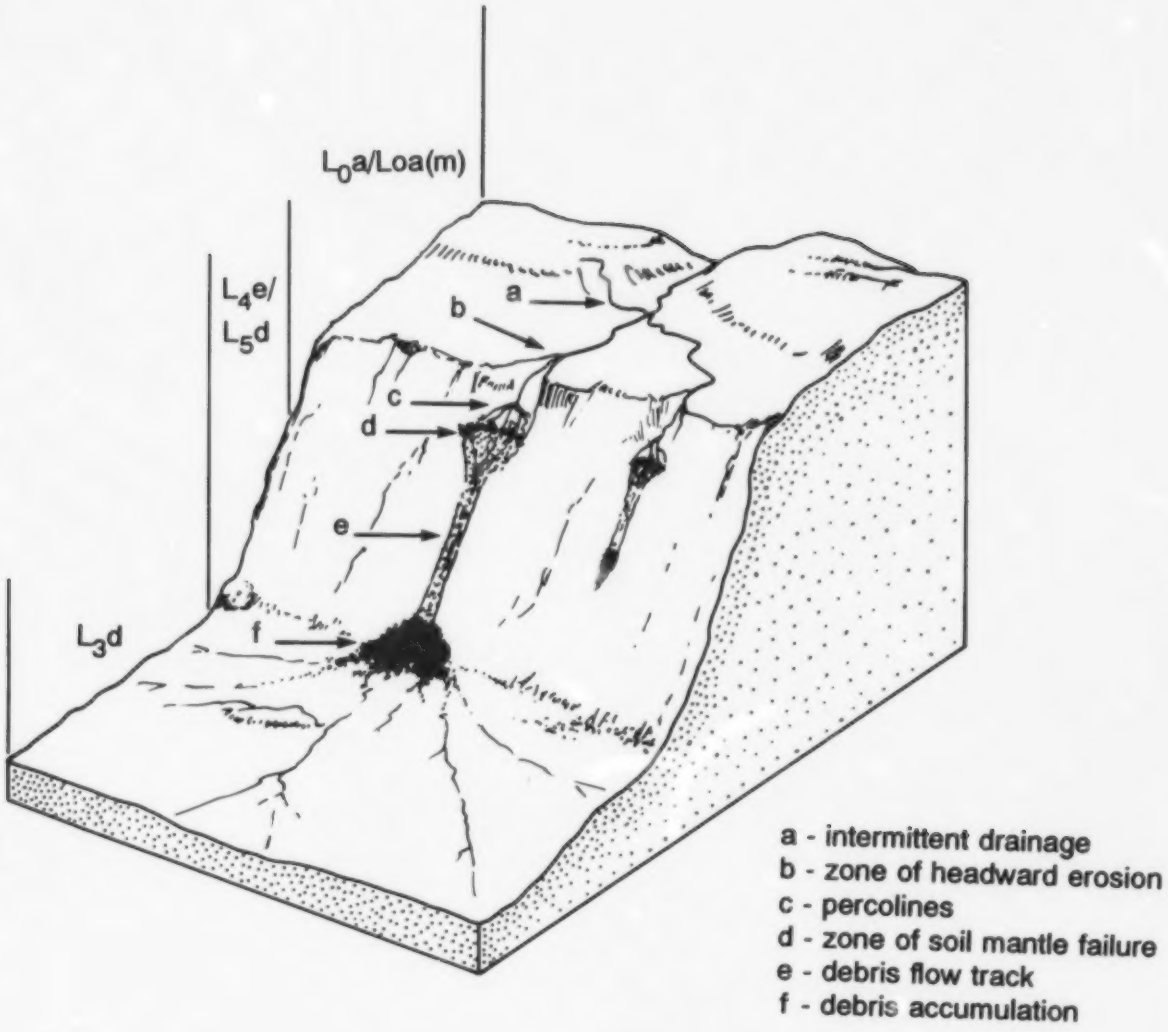


Figure 7. Mass movement - Type C.

dipped and generally uniform bedding structures can act as shear planes which promote "landslide" activity. Deep weathering of bedrock substrates may be promoted by groundwater flow through bedding planes. Additionally, overland flow from summits can contribute to subsurface soil seepage in upper slope ecosites.

Figure 6 (i) presents a typical catenary sequence of ecosites which could be subject to mass movements of type B. Ecosites $L_{oa(m)}$ and L_{5d} are at some initial time stable, but underlain by a weathered zone. A typical rock type for this scenario would be an area of shale. Figure 6 (ii) depicts a "landslide" occurrence with ecosites $L_{oa(m)}$ and L_{5d} subject to subsequent parallel slope retreat. Soil and weathered bedrock materials can be moved downslope but often with reduced energy compared to mass movements of type A. Lesser energy results primarily from the structural characteristics of the sedimentary detritus in terms of shape and reduced sizes. Additionally, colluvium may be less evident on lower slope positions resulting from faster weathering rates.

Figure 6 (iii) presents a typical catenary sequence of ecosites on a slate rock type without a weathered zone. The bedrock-soil interface can act as a shear plane over which soil mantle failure may occur. This "landslide" type may be promoted by increased soil pore pressures resulting from extreme rainfall and/or snowmelt events. Overland flow generated on the L_{oa} and $L_{oa(m)}$ ecosites may be translated into critical subsurface flow magnitudes in the L_{5d} ecosite. Resultant increases in soil pore pressure above threshold limits could result in soil mantle failures. Additionally, timber harvesting effects, such as increased soil water content and declining root strength, could combine with extreme climatic events resulting in this "landslide" activity. These potential effects have been noted by a number of researchers (Sidle 1985, Harr 1986, 1981, Swanston 1971, 1969).

Type C mass movements (Figure 7) can occur on varied lithologies, generally in the absence of a deeply weathered regolith and the presence of abrupt discontinuity between soil and bedrock. Various slope morphologies can result in convergence of percolines. In these concentration zones rapid debris flows and torrents may occur as the soil mantle becomes saturated.

Figure 7 presents a typical catenary sequence of ecosites with potential for debris flows. Ecosites L_{oa} and $L_{oa(m)}$ can act as an overland flow source area which translates into subsurface flow in ecosites L_{5d} or L_{4e}. Concentration of this subsurface flow can trigger the "landslide" activity. Individual flow tracks may expand through successive events. Additionally, individual flow tracks may coalesce.

4.3 Water Yield Analysis

4.3.1 Catchment level

Results of the hydrological analysis for the full catchment area are presented in Table 6. These results represents an approximation of the relative percentage contribution to annual water yield from the ecosite types mapped in the catchment.

4.3.2 Eastern Lake subcatchment

Results of the hydrological analysis for the Eastern Lake subcatchment are presented in Table 7. These results represent an

Table 6. Water yield at the catchment level.

Ecosite Type	Water Yield Rank	Area (ha)	% Water Yield
L_{oa}	37.30	1375.84	78.28
$L_{oa(m)}$	100.00	33.50	5.11
L_{1b}	0.18	93.80	0.026
L_{1c}	0.96	19.66	0.029
L_{2b}	0.0026	232.58	0.00009
L_{2c}	0.18	692.30	0.19
$L_{2c(o)}$	0.0005	144.59	0.00012
L_{2d}	0.28	312.73	0.13
$L_{2d/d(o)}$	2.46	128.51	0.48
L_{2e}	0.44	1331.35	0.89
$L_{3c(o)}$	0.000007	589.77	0.0000061
$L_{3c(l)}$	0.07	11.17	0.0011
L_{3d}	0.54	1809.08	1.49
$L_{3d(o)}$	0.000019	246.31	0.0000072
$L_{3d/d(o)}$	5.59	777.29	6.63
L_{3e}	0.81	111.54	0.14
$L_{4c(o)}$	0.000003	50.91	0.00000023
$L_{4c(l)}$	0.00037	10.61	0.0000059
L_{4d}	1.40	366.42	0.78
$L_{4d(o)}$	0.00005	16.36	0.0000076
$L_{4d/d(o)}$	7.79	58.94	0.70
L_{4e}	5.90	150.95	1.36
L_{5d}	3.93	334.07	2.00
$L_{5d/d(o)}$	10.00	115.55	1.76

Table 7. Water yield from the Eastern Lake subcatchment.

Ecosite Type	Water Yield Rank	Area (ha)	% Water Yield
L_{oa}	37.30	616.69	84.01
$L_{oa(m)}$	100.00	11.12	4.06
L_{1b}	0.18	11.34	0.0073
L_{1c}	0.96	7.44	0.026
L_{2b}	0.0026	1.60	0.000015
L_{2c}	0.18	104.42	0.069
$L_{2c(o)}$	0.0005	19.69	0.000036
L_{2d}	0.28	57.28	0.058
$L_{2d/d(o)}$	2.46	15.44	0.14
L_{2e}	0.44	342.02	0.55
$L_{3c(o)}$	0.000007	97.86	0.0000025
$L_{3c(f)}$	0.07	1.75	0.00044
L_{3d}	0.54	335.32	0.66
$L_{3d(o)}$	0.000019	78.57	0.0000055
$L_{3d/d(o)}$	5.59	262.83	5.37
L_{3e}	0.81	31.41	0.091
$L_{4c(o)}$	0.000003	17.05	0.00000019
$L_{4c(1)}$	0.00037	17.05	0.0000027
L_{4d}	1.40	126.55	0.65
$L_{4d(o)}$	0.00005	6.19	0.0000011
$L_{4d/d(o)}$	7.79	23.55	0.67
L_{4e}	5.90	50.37	1.08
L_{5d}	3.93	34.40	0.49
$L_{5d/d(o)}$	10.00	56.73	2.07

approximation of the relative percentage contribution to annual water yield from the ecosite types mapped in this area.

5.0 DISCUSSIONS

5.1 Limitations of the Application

Application of ecosite mapping as documented in this study has a number of inherent limitations. Absolute intensities or magnitudes of soil and site degradation are not predicted by the methodology. Presently, for Newfoundland conditions, empirical soil and site degradation data resulting from specific disturbance types on differing ecosites is not available. The sensitivity ratings infer that for specific disturbance types intensities of degradation will be proportional to the rating of the ecosites. Additionally, the areal extent of soil and site disturbance resulting from logging activities is not predicted. Correlations between disturbance extent and terrain types may exist, however, these relationships may be weak or obscured due to variability in operational practices and logging methods (Case and Donnelly 1979, Krag *et al.* 1986).

The sensitivity rating of each ecosite is considered to be discrete and independent of its spatial and areal relationships with other ecosites. However, feedback effects due to mass and energy fluxes between ecosites do occur, especially with respect to boundary conditions. In the absence of empirical data, quantification of these effects cannot be attempted. Interpretations can however, be made to identify specific ecosites where sensitivity levels may be amplified or moderated.

Sensitivity ratings also assume that erosivity factors are at unity. Absolute intensities of erosion may therefore vary from one climate region to another for the same ratings. However, by assuming erosivity to be a unity factor the method can be applied within relatively small areas subject to mesoscale climatic regimes. Additionally, vegetative cover factors are considered to be at unity.

The sensitivity ratings of ecosites are interpreted independently of area, geographic location and forest productivity. Polygons of "special" concern because of a combination of sensitivity and location may be "flagged" as requiring added consideration.

Finally, distinction is necessary between sediment delivery potential and sediment yield. Ecosites may be inferred to have sediment delivery potentials due to inherent properties. However, in the absence of interfacing streams or water bodies no sediment yield is considered to occur.

5.2 Soil and Site Degradation

Potential for non-erosional and erosional soil and site degradation can be generally related to three factors:

1. The ecosite properties.

2. The disturbance type.

3. The spatio-temporal characteristics of the disturbance type pattern on the ecosite.

Ecosites are defined and ranked for sensitivity on the basis of soil textural, slope gradient and soil moisture/groundwater characteristics (van Kesteren 1986). Combinations of these parameters will determine

the potential of differing ecosites to incur soil and site degradation.

Soil and site degradation may be incurred from various disturbance types. Differing disturbance types will have varying consequences for soil and site degradation. For example, a bulldozed skid trail because of initial mineral soil exposure, will generally result in a greater soil and site degradation than an unbulldozed skid trail on a given ecosite.

Specific disturbance types such as bulldozed skid trails will have variable spatial and areal configurations on a given ecosite. The intensity of soil and site degradation will therefore vary in relation to the characteristics of the disturbance type pattern and time since disturbance. A simple example of this principle would be a bulldozed skid trail perpendicular to contour producing more intense soil erosion than a bulldozed skid trail parallel to contour on the same ecosite. Additionally, a severe disturbance factor on a low sensitivity ecosite could result in greater degradation than a less severe disturbance on a higher sensitivity ecosite.

Theoretically, minimum "safe" or acceptable levels of operation designed to offset degradation could be defined for various ecosite and disturbance type combinations. A lack of empirical data presently restricts a quantitative definition of these thresholds. It is clear however, that as the areal extent and severity of site disturbance is increased, potential for soil and site degradation will increase accordingly. This trend has been documented by a number of researchers (Cobourn 1989, Utizig and Walmsley 1988, Krag *et al.* 1986, Case and Donnelly 1977, Rothwell 1978).

5.3 Sediment Delivery Potential and Water Quality

Sedimentation has a direct relationship to soil and site disturbance factors (Rothwell 1978, Hornbeck and Reinhart 1964, Beschta 1978, Miller 1984). However, correct planning and operational layouts can reduce water quality impairment to safe or acceptable limits.

Ecosite disturbances comprise a sediment delivery potential which can contribute to serious water quality impairment. Sediments derived from disturbance factors can be cumulative within watersheds (Cobourn 1989). These sediments are often untraceable to a single point of origin and can be considered as non-point pollution. Cumulative fluxes of sediment can result from contiguity or linkage of disturbance factors. A simple example would be of several downslope skid trails converging to a vertex. A single trail could then originate from this point and lead to a roadside landing. Clearly, this disturbance type pattern could provide a ready network for sediment transport. Reduction of linkages provides a means of reducing runoff quantity, intensity and subsequent sediment concentration.

Sedimentation can occur naturally in watersheds in the absence of soil and site disturbance factors. Discharge maxima or minima can result in successive periods of bank erosion, channel scour and aggradation. Soil and site disturbances could amplify these processes through increased peak flows. The degree to which autochthonous stream loads could increase is a function of changes in flow regime and interactions with factors governing the stream channel strength. Prediction of these interactions is not possible in this analysis.

However, stream channel morphology in the Corner Brook Lake watershed is primarily the result of a bedrock structurally controlled glacial terrain. It could be expected that this terrain type will contribute to natural stability of the stream network and moderate the potential for riparian sediment delivery.

Disturbance factors created in riparian zones are critical point sources of sediment delivery. Disturbances in these locations can act as direct pathways for sediment delivery through channelized or sheet flow erosion. Additionally, a disturbance factor could result in a loss of natural stability in the riparian zone. Interactions of the stream and disturbance factor during peak discharges could therefore contribute significantly to sediment yields.

5.4 Water Yield

5.4.1 Basic concepts

The principle of water yield can be demonstrated by a simple three factor equation representing a continuity or balance approach:

$$P = E + \Delta r \quad \text{(Oke 1978)}$$

The parameters in the equation are:

P = precipitation in all forms
E = evapotranspirative losses
Δr = net runoff (water yield)

The equation can be transposed as shown:

$$\Delta r = P - E$$

Runoff may attain a positive or negative value depending on the magnitudes of the terms P and E. Thus, precipitation inputs must exceed evapotranspirative outputs in a hydrological system to produce a water yield. An important principle in this approach is that Δr is a continuous non-stationary variable resulting from complex spatio-temporal lags associated with the translation of a given water mass through a hydrological system. Spatio-temporal lags can be attributed to a complex of storage factors. The water balance equation can be rewritten to include these factors:

$$P = E + \Delta s + \Delta r \quad \text{(Oke 1978)}$$

The term Δs, represents storage parameters such as soil moisture. As with Δr, Δs is also a continuous variable. Changes in storage will occur as the Δs quantity is partitioned through exchange processes with E and Δr.

A watershed may be conceptualized as a simple input-output system. Hydrologic inputs will be translated through the watershed resulting in an output or water yield. It could be expected that throughputs and outputs, for given input regimes will be deterministically related to the physiographic properties of the catchment. This principle has been demonstrated for hydrograph analysis of various catchment types and climatic regimes (Dunne and Leopold 1978, Bedient and Huber 1989). To the degree that differing catchment parameters may be identified and defined, specific land response units or source areas of varying water yield magnitudes could be delineated and used to infer a partitioning of water yield magnitudes through characteristic basin processes. In the short term partitioning magnitudes could be difficult to predict as interactions

between varying inputs and physiographic conditions could result in complex spatio-temporal lags. The integration of spatio-temporal lags over the long term would however, theoretically enable a calculable balance through system continuity.

5.4.2 Literature review

A brief review of literature indicates that clearcutting results in increased water yields. Hibbert (1966) and Bosch and Hewlett (1982) summarized the results of many studies which demonstrated increased water yield from forest cover reductions. Rothacher (1970) concluded that annual water yields increased in proportion to the area clearcut. Additionally Rich and Thompson (1974) reached similar conclusions. Bell *et al.* (1974) concluded that forest harvesting generally results in increased water yields and stream flows. "The Environmental Effects of Forestry Operations in Alberta" (Anon. 1979) indicated annual stream flow increases in the order of 20 to 80 percent as being possible for watersheds which are harvested.

Studies of water yield have largely been conducted on small experimental watersheds where harvest can be undertaken in a short time frame. On large operational watersheds increases in water yield may not be salient in high order streams (Rothacher 1970). Staggered cutting operations of small percentages of the total area can occur over a number of years. Previously cut areas which regenerate sufficiently may offset yield increase contributions from recent cut blocks. Thus, increases in water yield may only be detectable in the discharge regimes of low order streams proximate to recent cut areas of the basin. Rothacher (1971) also concludes that increased minimum flow levels during dry summers can occur from cutting, but such increases may fall within the range of flows associated with normal climatic variation.

Case studies indicate that water yield increases are short term (Rothacher 1971). Cline *et al.* (1977) report that gains in water yield were offset by increasing evapotranspiration rates from regeneration of cut areas after four years. Bell *et al.* (1974) cite a 1952 U.S.D.A. reference which reports water yield increases swiftly diminishing during the first three years following harvesting. However, other sources indicate that small but significant water yield increases can continue 30 years or longer after cutting (Kovner 1956, Leaf and Alexander 1975).

Variation in the magnitude and timing of water yield increases is also indicated in the literature. Concentration of increases often exhibit some lag effect but general coincidement with seasons of greatest rainfall and/or snowmelt. This is generally in accordance with accepted hydrological principles (Chow 1964, Ward 1975). Variation in hydrologic behaviour of watersheds among case studies is largely attributable to differences in physiographic conditions (Rich and Thompson 1974). Physiographic differences within watersheds thus provides a basis for land response unit or source area analysis in hydrology (Hewlett and Hibbert 1967, Gregory and Walling 1976, Ward 1975, Van De Griend and Engman 1985).

5.4.3 Water yield changes

Under present climatic conditions high runoffs are characteristic of Newfoundland drainage basins (Yoxall 1981). The Corner

Brook Lake watershed is located in the West Coast climatic zone of Newfoundland. Annual precipitation of 1000-1200 mm and a runoff of 569 mm, including snowmelt (Banfield 1983), could be anticipated to support a secure water supply. Although it is unlikely that forest harvesting will jeopardize security of gross water supply, there could be changes in spatial and temporal partitioning of water yield. Such changes are dependent on a number of factors:

1. The number of hectares and time frame proposed for harvest.

2. The location of areas proposed for harvest.

3. The natural water yield characteristics of areas proposed for harvest and the degree to which these characteristics may be changed from soil and site disturbance factors.

Generally, an increase in area of harvest and shortening of time frame will result in increased potential for changes in water yield partitioning. Reduction of total area of cut and distribution of smaller cut blocks throughout a watershed can mitigate against potential watershed disturbance (Rothwell 1978).

Increases in water yield have important implications for water quality. If relatively small areas are harvested the water yield increases will likely also be relatively small. However, these yield increases could result in significant increases in discharge regimes for small intermittent and first order streams. Such increases from small cut areas may not be salient and easily detected in higher order streams. However, the interaction of increased discharge regimes with disturbed soil (e.g. skid trails crossing small streams) conditions could contribute to problems with water quality maintenance.

6.0 RECOMMENDATIONS

6.1 Operational Guidelines

Operational guidelines designed to offset soil and site degradation and sediment delivery potential are presented below. These guidelines are cross-referenced to ecosite types in Table 8. As additional guidelines based on refined knowledge are developed, these can also be applied. Operational guidelines are as follows:

1. Guidelines specified in the publication "Resource Road Construction: Environmental Guidelines and Design Criteria" by McCubbin *et al.* (1985) will apply to all ecosites.

2. The higher the sensitivity level of an ecosite the more detailed the ground survey should be for road location and skid trail layout etc. This will help ensure environmental protection is implemented where most needed.

3. Logging, road construction, vehicle operation or related activities should be restricted to ensure sites are maintained in a natural undisturbed condition.

4. Logging and road construction should not be undertaken in the spring or during excessively wet periods. Winter, late summer and fall seasons are recommended for harvesting operations. Use of ice and snow road in construction techniques could considerably reduce soil disturbances.

Table 8. The relationship between operational guidelines and ecosite types.

Ecosite Type	Operational Guidelines
L_{oa}	1, 2, 5.1, 13
$L_{oa(m)}$	1, 2, 5.1, 13
L_{1b}	1, 2, 5.2, 12, 13, 25
L_{1c}	1, 2, 4, 5.2, 9, 10, 13, 25
L_{2b}	1, 2, 5.3, 12, 13, 25
L_{2c}	1, 2, 4, 5.3, 9, 10, 11, 13, 25
$L_{2c(o)}$	1, 2, 4, 5.3, 8, 9, 10, 11, 13, 25
L_{2d}	1, 2, 4, 5.3, 7, 11, 12, 13, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25
$L_{2d/d(o)}$	1, 2, 4, 5.3, 7, 9, 10, 11, 12, 13, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25
L_{2e}	1, 2, 5.3, 12, 13, 15, 25
$L_{3c(o)}$	1, 2, 4, 5.4, 8, 9, 10, 11, 13, 25
$L_{3c(l)}$	1, 2, 4, 5.4, 8, 9, 10, 11, 13, 25
L_{3d}	1, 2, 3, 5.4, 6, 6.1 to 6.11, 7, 11, 13, 14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25
$L_{3d(o)}$	1, 2, 4, 5.4, 6, 6.1 to 6.11, 7, 9, 10, 11, 13, 14, 16, 18, 19, 20, 21, 22, 23, 25
$L_{3d/d(o)}$	1, 2, 4, 5.4, 6, 6.1 to 6.11, 7, 9, 10, 11, 13, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25
L_{3e}	1, 2, 5.4, 6, 6.1 to 6.11, 7, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25
$L_{4c(o)}$	1, 2, 3, 5.6
$L_{4c(l)}$	1, 2, 3, 5.6
L_{4d}	1, 2, 4, 5.5, 6, 6.1 to 6.11, 7, 8, 11, 13, 14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25
$L_{4d(o)}$	1, 2, 4, 5.5, 6, 6.1 to 6.11, 7, 8, 9, 10, 11, 13, 14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25
$L_{4d/d(o)}$	1, 2, 4, 5.5, 8, 9, 6.1 to 6.11, 7, 8, 9, 10, 11, 13, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25
L_{4e}	1, 2, 5.5, 6, 6.1 to 6.11, 7, 8, 13, 14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25
L_{5d}	1, 2, 3, 5.6
$L_{5d/d(o)}$	1, 2, 3, 5.6

5. Buffer strips of undisturbed ground vegetation, as indicated in Table 9, should be maintained in land-water interface zones. Bulldozing of soils is to be avoided. Timber removal from buffer zones by winching will reduce machinery movement to minimum levels.

6. Cable logging is recommended. Under economic or technological constraints the following subguidelines should be considered.

   6.1 Bulldozed skid trails are to be kept to a minimum number and areal coverage. Unbulldozed extraction routes should be used where feasible.

   6.2 Efforts should be made to utilize available machinery technology for the goal of reducing soil disturbance. Machinery such as skidders with low ground pressure tires may allow for safer operation in the absence of bulldozed skid trails.

   6.3 Skid trail cut depths should be kept to a minimum. Deep bulldozing into lower B and C horizons disrupts natural soil structure and can result in severe erosion and sediment delivery potential.

Table 9. Recommended buffer strips.

	Sensitivity Level	Ecosite Groups	Buffer strip (metres)
5.1	L_0	a, a(m), b	20
5.2	L_1	b, c, d, e	20
5.3	L_2	b, c, c(o), c(1), d, d/d(o), e	30
5.4	L_3	c, c(o), c(1), d, d(o), d/d(o), e	50
5.5	L_4	d, d(o), d/d(o), e	115
5.6	L_4	c(o), c(1)	*
5.6	L_5	d, d(o), d/d(o)	*

* For sensitivity ratings of L_4 c(l), L_4 c(o), and all L_5 levels guideline "3" is to be followed. If the width of the ecosite is less than 115 metres, the buffer zone should include not only the natural boundary of the ecosite but an additional swath from the adjoining unit such that a 115 metre buffer is maintained.

6.4 Skid trail cut depths should be minimized and kept constant. Increasing cut depths can initiate severe erosion through changes in the gradient of the skid trail. This is a critical factor when cut depths are increased in downslope segments of skid trails.

6.5 Skid trails should cross slopes parallel to contour. Switch-backs should not be deflected from contour more than 15°. If constant cut depths are maintained the gradient of the skid trail will be approximately equal to 1/6 of the prevailing slope gradient.

6.6 Switchbacks should not exceed 50 metres in length. There should be no contiguity or junction of these downslope trails. Switchbacks should join cross contour skid trails and where possible these junctions should be horizontal.

6.7 Horizontal junctions can be accomplished by decreasing the cut depth on the downslope segment of the trail. Horizontal junctions should not be constructed through backfilling of disturbed soil. Figure 8 presents an illustration of this construction technique.

6.8 Where downslope skid trails exceed 50 metres in length, a decrease in cut depth as illustrated in Figure 8 should be considered. This results in "rolling the grade" of the skid trail surface with a dissipation of erosive power of runoff and upslope sediment trapping. The structure should not be achieved by backfilling of disturbed soil materials, rather through a maintenance of the natural soil structure achieved from cut depth reduction.

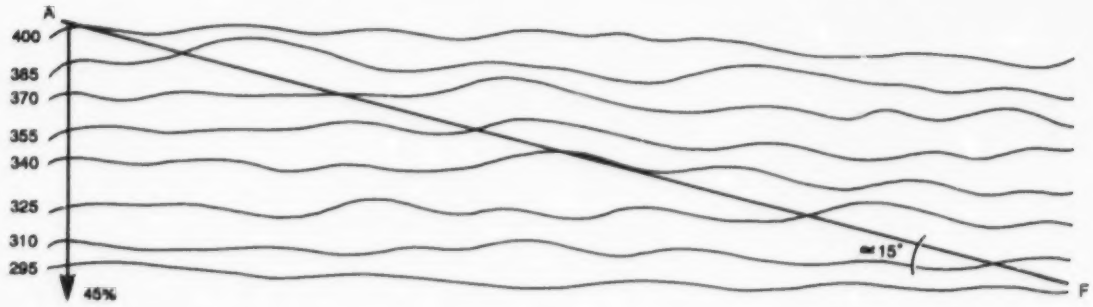
6.9 Skid trails should have a cross sectional profile as shown in Figure 9. Three major elements of the skid trail should be the cut slope, trail running surface and side cast slope. This profile will aid in dissipating runoff waters from the skid trail. Skid trail cross sections of a V or U shape should be avoided. The tendency to construct trails with U or V shaped cross sections increases with increasing angle of deflection from contour.

6.10 Skid trails should follow a general plan as shown in Figure 10. Upper limits of slope operability should be located in the field. This general pattern is to be applied with consideration to the previous subguidelines.

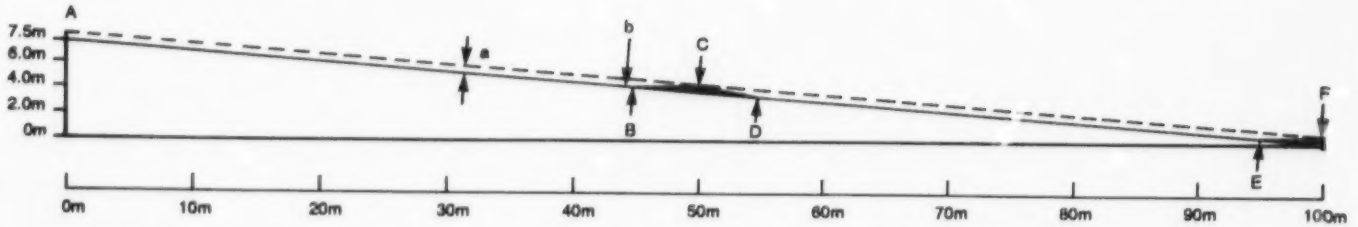
6.11 Cutting upper slope timber initially and maintenance of stands in lower slope positions may mitigate against sediment delivery potential. Where feasible lower slopes follow the initial cutting of upper slope stands by two to three years.

7. Road, skid trail and landing locations should avoid significant breaks of slope between adjoining ecosites. This principle is shown in Figure 11. The break of slope between the L_{3d} and L_{4d}

Contour Plan (not to scale; Contour Interval = 15m ≃ 50ft; Average Slope is 45%)



400 ~ Contours
AF Skid Trail Surface
≃(Deflection Angle from Contour

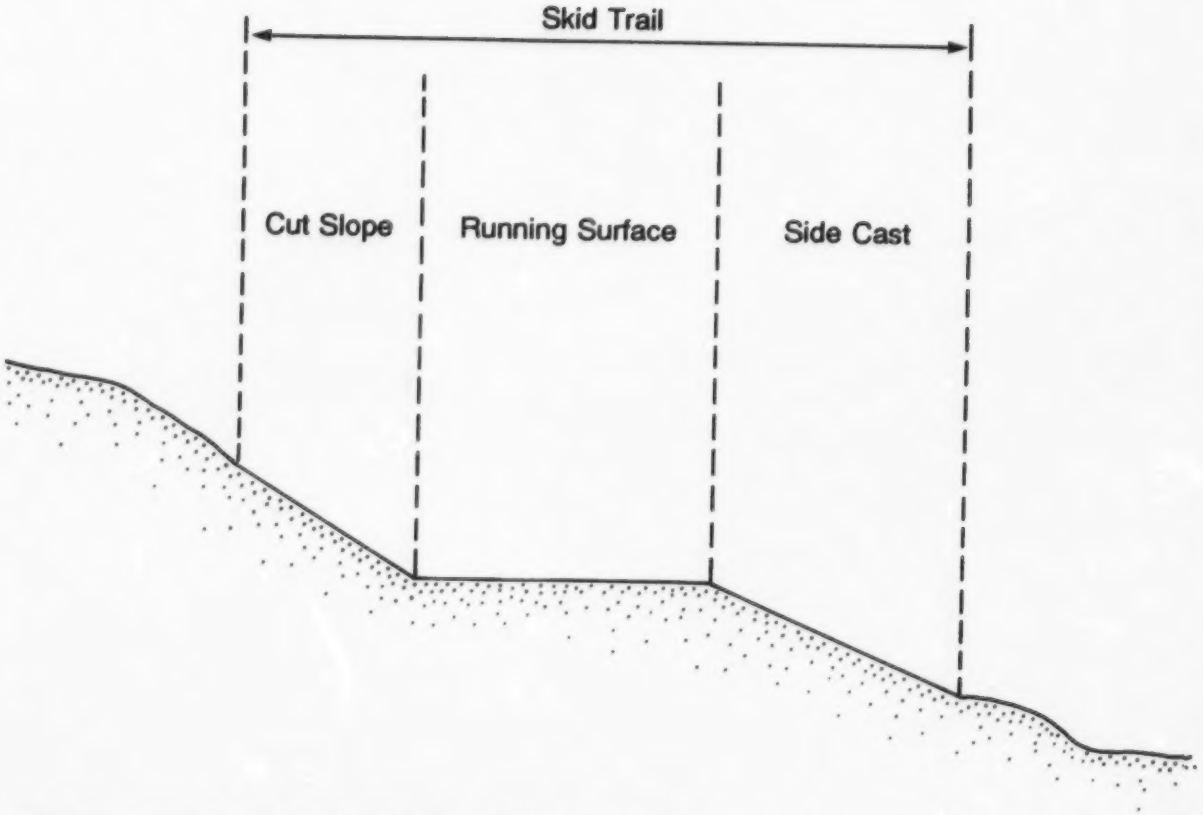


Profile Plan (1cm = ≃ 5m)

--- Initial Ground Surface
AF Skid Trail Surface; Trail is Deflected 15° from Contour; Trail Slope Gradient = 7.5%
a Constant cut depth of 0.5m
b Sediment Trap
BCD Erosion Control Structure; BC and CD are 5.0m in Length with 10% Slope i.e. 0.5m Rise in 5.0m; Point C is at Ground Level
EF Horizontal Join to a Contour Skid Trail

Note: Erosional Potential Will Decrease as Cut Depth, Deflection Angle and Trail Length are Decreased.

Figure 8. Skid trail construction techniques.



Running surface width should be minimized but allow for machinery stability and safety. Increased running surface widths result in deeper slope excavation and more soil disturbance. Where possible and within safety limits running surfaces should be sloped (crowned) towards side cast to aid in surface drainage.

Figure 9. Skid trail construction techniques.

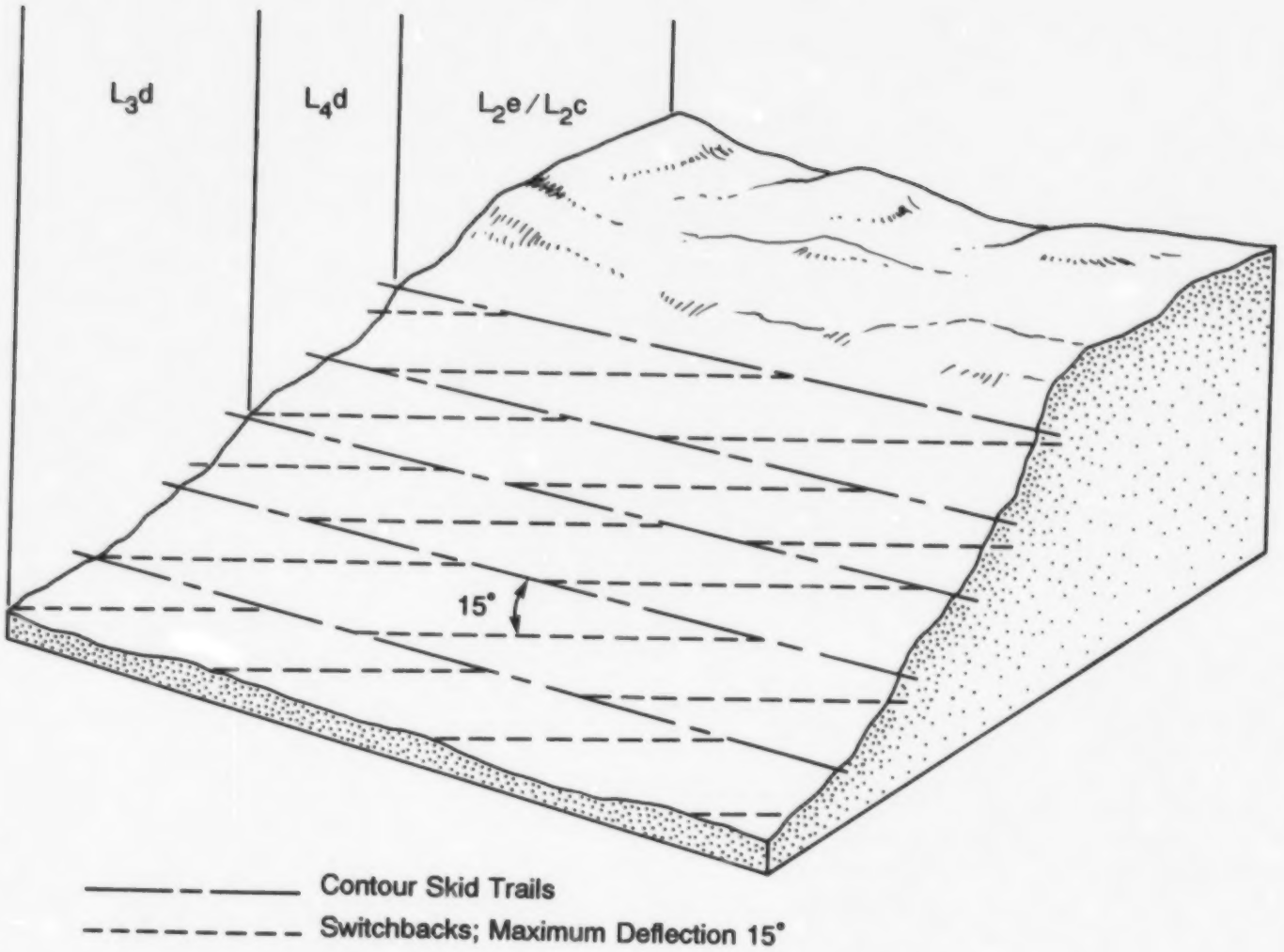
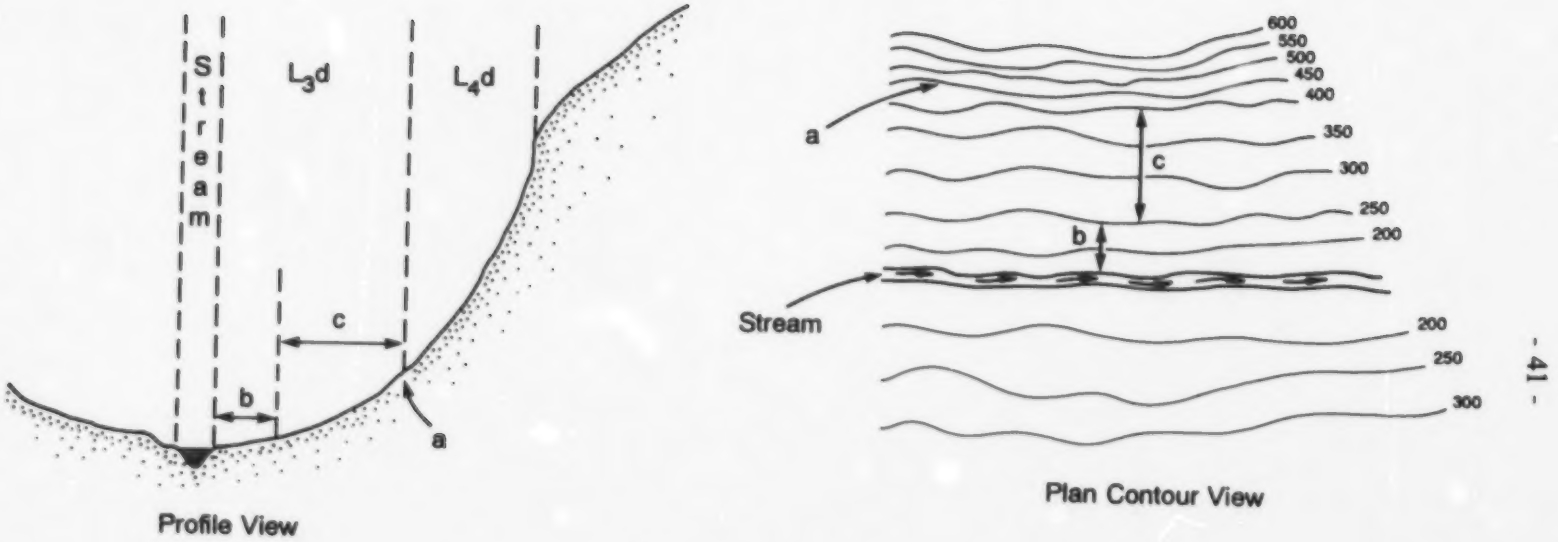


Figure 10. Generalized skid trial location.



a - break of slope
b - buffer zone
c - general zone for road location

Figure 11. Road and skid trail location.

ecosites is a zone where subsurface seepage can intersect the ground surface. This boundary condition can be a critical location for the initiation of severe erosion. Inherent reductions in trafficibility due to wetter conditions may also be characteristic.

8. Bridge locations are not recommended.

9. Road locations are not recommended. Excavation of peat soils, brushmatting and use of good subgrade materials may be required to increase road bearing capacities.

10. Location of timber landings should be avoided.

11. The number of machine passes per skid trail should be minimized to reduce soil compaction, deformation and impoundment of water.

12. Unbulldozed skid trails are recommended with a minimum number of machine passes per trail to reduce soil compaction. Trail patterns may be random as dictated by harvestable timber stands.

13. Avoidance of ground disturbance in areas of noncommercial or nonmerchantable timber stands is desirable. Noncommercial hardwood stands should be left standing if they do not conflict with access to harvestable timber.

14. Road, skid trail, and landing locations should utilize less sensitive ecosite types that occur within the boundaries of a higher sensitivity ecosite. Figure 12 demonstrates this principle.

15. Skid trails should spiral the contour pattern of short slope sites. Avoidance of trails perpendicular to contour is desirable. Figure 13 demonstrates this principle for a typical L_{2e} ecosite.

16. Road and ditch longitudinal profiles on these ecosites can be a source of discharge and sediment delivery. Therefore, adequate culverting and road cross drainage is critical.

17. Junctions of roads and downslope skid trail segments can result in road and culvert washouts. Subguidelines 6.7 and Figure 8 should be considered as a construction technique. Horizontal junctions will help to reduce discharge velocity and sediment delivery to ditches.

18. Burrow pits should be constructed on upslope sides of road locations. Adequate buffers between the burrow pit area and road should be maintained. Burrow pit surfaces should not be sloped to channel runoff to ditches and road surfaces. Cross slope drainage of burrow pits is desirable. Figure 14 suggests some principles in burrow pit construction to reduce discharge and sediment delivery potential.

19. Timber landings in proximity to roads should follow similar principles to burrow pit construction as shown in Figure 14 and guideline 18.

20. Where possible first and second order streams should be used as natural boundaries for cut blocks. Crossings of these streams by skid trails should be minimized.

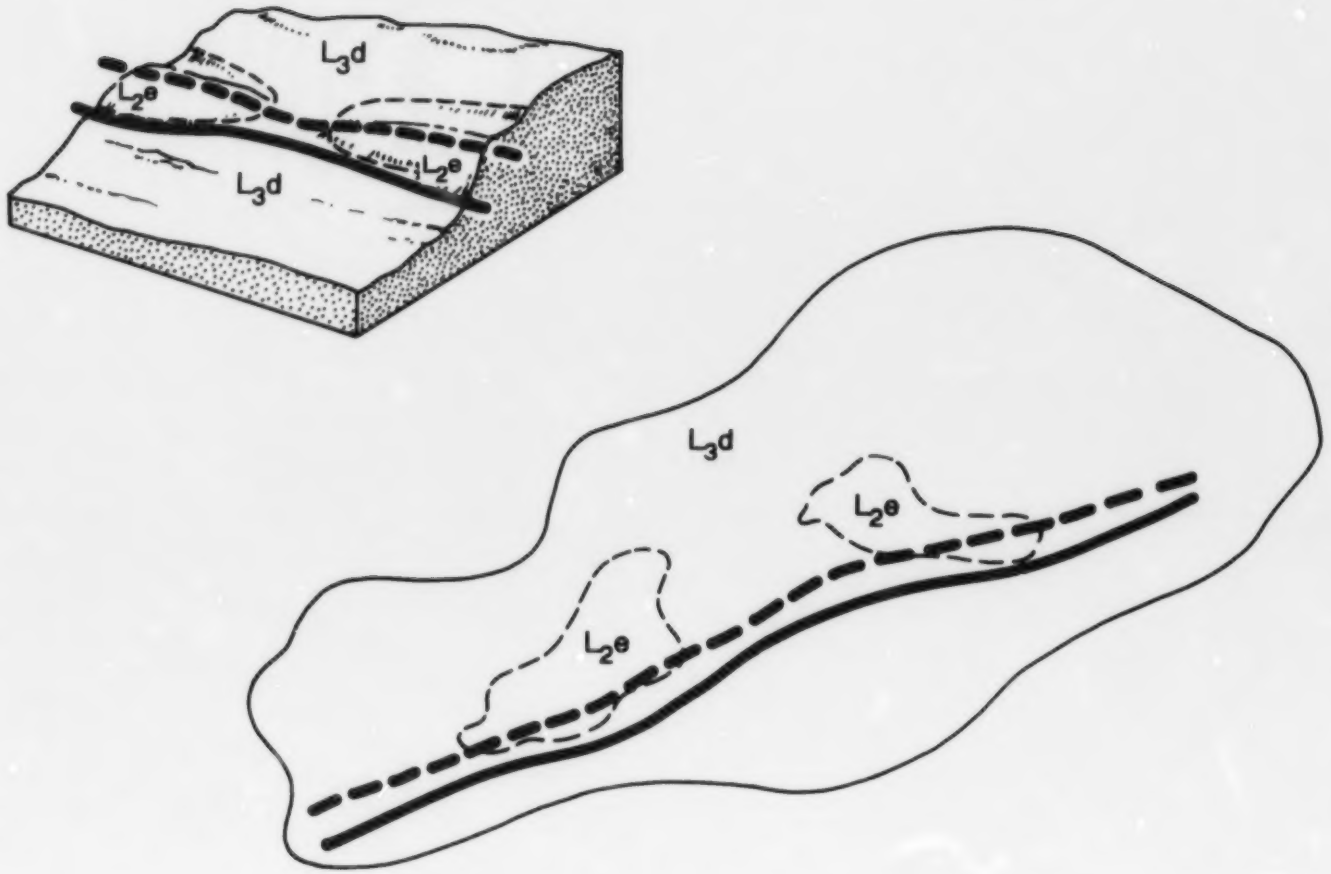
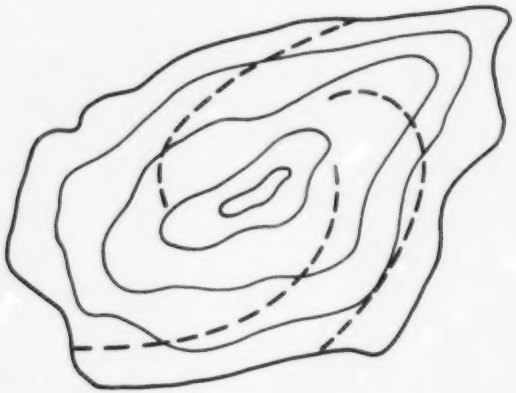


Figure 12. Road and skid trail location.

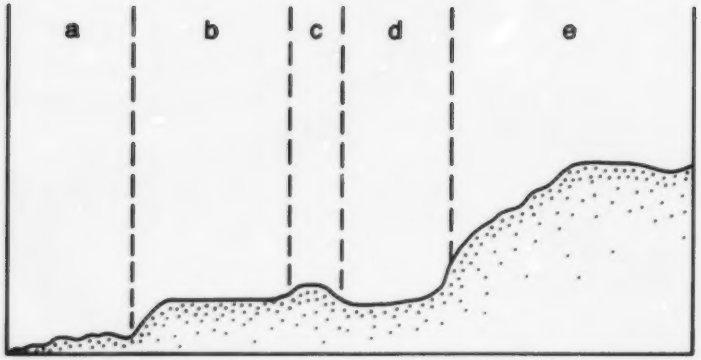


Contour View - L_2e

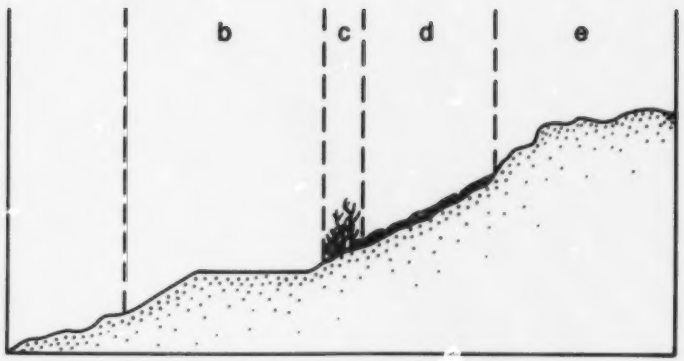
Profile View - L_2e

- - - Skid Trail Locations

Figure 13. Road and skid trail location.



Deep Burrow Pit
a - lower slope
b - road crossection
c - berm of undisturbed soil materials, (not backfilled) will control runoff onto road surfaces
d - burrow pit drainage should be out of the pit in a cross slope direction
e - upper slope



Shallow Grubbing Area
a - lower slope
b - road crossection
c - buffer strips of undisturbed ground vegetation, with gap "x" to allow for machinery operation
d - shallow grubbing area
e - upper slope

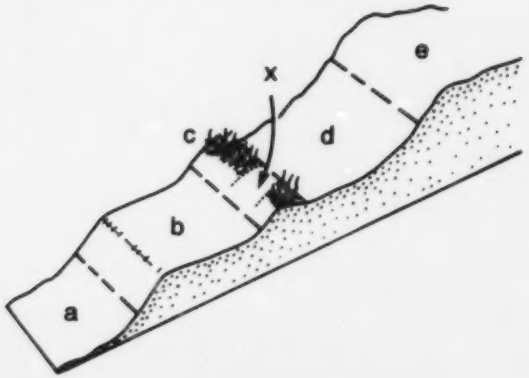


Figure 14. Burrow pit and grubbing area construction techniques.

21. When skid trail crossing of streams is required, pre-selected and set locations should be used. This selection process should be a part of the skid trail and road network plan.

22. Low slope gradient stream crossings should be chosen. Bulldozing of approaches should be avoided. Temporary bridging and/or brushmatting of approaches to small streams may be necessary to reduce disturbance to surface vegetation and sediment delivery potential.

23. Approach and crossing of streams should be made from contour skid trails. Crossings from downslope skid trail segments should be avoided.

24. Timber in deeply incised natural stream channels should not be harvested except where necessary to allow for a stream crossing point.

25. Bulldozing and skid trail construction utilizing intermittent or ephemeral stream channels as part of the location must be avoided. High intensity spring runoff could be diverted from the disturbed channel to the skid trail resulting in severe sediment delivery potential.

6.2 Contingency Strategies

Project flexibility and planning efforts arise from the available data base information (e.g., forest inventory maps, ecosite maps, etc.). Application of these data bases will reduce the incidence of on-site remedial measures, while contingency strategies provide a framework for addressing problems which may arise in spite of planning efforts.

The following contingency strategies are recommended:

1. On-going operations should be monitored. Monitoring personnel should be informed on location and timing of specific project phases, allowing adequate preparation to review data bases and potential impacts.

2. Monitoring personnel can priorize efforts by project phases and locations with the greater potential hazards.

3. All on-site personnel should assume a high level of responsibility for general monitoring. Information sessions and meetings for operations personnel will promote the objectives of environmentally sound project implementation.

4. On-site chains of responsibility of key personnel should be in place to expedite decisions on halting or modifying operations when problems arise or appear imminent.

5. Operations personnel should maintain up to date records of harvest zones, road locations, refueling sites, etc. This will provide a communications link with monitoring personnel. Additionally, it may provide a basis for location of point sources of sedimentation or other pollutants.

6. Personnel, machinery and materials needed to address specific environmental problems should be available for quick mobilization (e.g., mulches to

reduce erosion, containment materials for oil spills, etc.)

7. Monitoring efforts may need to be continued after harvest operations are completed. For example severe skid trail erosion might not occur for several years after the initial disturbance.

8. Monitoring after operations have ceased may reveal the necessity of implementing site rehabilitation. Emphasis should therefore be directed towards planning at the "front end of the project" where investments will be much less. Costs have been shown to be in the order of $200 to $450/ha versus $1000 to $5000/ha for planning versus rehabilitation (Utizig and Walmsley 1988).

9. A record of the types of problems encountered and the efficacy of remedial measures should be kept. This will serve to strengthen future planning efforts and contingency strategies.

10. Periodic road maintenance will contribute to reductions in sediment delivery potential as well as allowing access to the area for future watershed and forest management objectives.

11. Water quality monitoring should be continued and expanded if necessary.

7.0 CONCLUSIONS

It is concluded that timber harvesting and subsequent forest management practices can be compatible with watershed management objectives in the Corner Brook Lake watershed. Planning, guideline implementation and contingency strategies are necessary to ensure water quality maintenance and reductions in soil and site degradation. Annual water yield magnitudes from the watershed will likely be maintained or have small increases as harvest operations proceed.

The relatively low percentage of land base proposed for exclusion from timber harvest does not imply low concerns for the remaining land area. Approximately 3545 ha (39.33% of the land base) fall in classes designated as high sensitivity and some 654 ha (7.26% of the land base) fall in classes designated as very high sensitivity. These areas although considered acceptable for harvest indicate the necessity of implementing operational guidelines to reduce potential negative impacts in the water supply area. Poor operational practices carried out on lower sensitivity land could also result in more serious impacts than sound practices on higher sensitivity lands.

The land sensitivity assessment of the Corner Brook Lake watershed has been achieved through application of a relatively simple method as described by van Kesteren (1986). Quantitative data on the intensity and extent of timber harvesting impacts cannot be presently derived from this methodology. However, the classificatory approach achieved in this method provides a planning data base as well a stratification for future modelling and empirical impact prediction.

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APPENDIX I

Relative Soil Erodibility

It is known that for various surficial landforms certain textural ranges of soil can be inferred in light of past and presently occurring processes. The identification of specific genetic categories of landforms can therefore provide a basis for predicting soil texture and consequent erodibility levels. However, the range of soil textures associated with different categories of landforms is often wide, with intra- and intercategory overlaps being common. These naturally occurring overlaps necessitate definition of relative soil erodibility within a minimum number of levels to facilitate an application through air photo interpretation.

Four levels of relative soil erodibility have been designated:

E_0 - None
E_1 - Low
E_2 - Moderate
E_3 - High

The relationships of these erodibility levels to pedologic and geomorphic conditions are shown in Table 1.

APPENDIX II

Slope Classes

Six slope classes have been utilized:

S_0 - negligible	(0-5%)
S_1 - low	(6-15%)
S_2 - moderate	(16-30%)
S_3 - high	(31-45%)
S_4 - very high	(46-60%)
S_5 - extreme	(>60%)

Two general slope forms are recognized when determining the gradient: simple slopes and complex slopes. Simple slopes rise uniformly from a minimum elevation to a maximum, which is clearly discernable at a point where the summit morphology becomes dominant. Simple slopes are also characterized by few significant breaks in gradient. The gradient of a simple slope can be estimated from the change in elevation and expressed as a percent.

Complex slopes are series of slopes, summits and intervening valleys which reoccur in recognizable patterns of symmetry and/or asymmetry, which distinguishes them from other landscape features. The slope class for such complex patterns can be estimated as the average gradient of the major components comprising the pattern expressed as a percent.

APPENDIX III

Groundwater Classes

The term "groundwater" has been used generally in this report and includes the following conditions:

1. True groundwater, the level of which undergoes vertical fluctuation in the soil profile and can thus influence the zone of aeration.

2. Interflow (also referred to as subsurface flow or seepage) in which lateral movement of soil water is dominant and percolation to the true groundwater table is restricted by indurated soil layers or bedrock.

3. Perched soil water resulting from restriction of percolation and lateral movement due to topography, indurated soil layers or lithic contacts.

4. Periodic inundations of significant duration arising from:

   a. increases in stream and lake levels during periods of high precipitation or storage (ice and snow melt) inputs.

   b. intermittent and ephemeral stream flow and any associated surface accumulations resulting from direct and storage inputs.

Three groundwater classes and one subclass are recognized: G_0, G_1, G_2, and G_2 (i).

Groundwater Class G_0 - Characterized by an absence or near absence of true groundwater, interflow or perched soil water in the soil profile. Soils are very rapidly to moderately well drained, soil moisture content does not usually exceed field capacity except for short durations after heavy rainfalls. The true groundwater table and capillary fringe are usually present at deep levels below the taxonomic profile.

Groundwater Class G_1 - Characterized by a predominant interflow of soil water. Lateral seepage is largely controlled and maintained by gradient, slope length and the presence of indurated soil layers or bedrock. Vertical percolation is restricted resulting in soil moisture contents which are in excess of field capacities for long periods of the year. Soil drainage ranges from moderately well to poorly drained.

Groundwater Class G_2 - Characterized by restricted lateral seepage and vertical percolation, thus leading to the development of a perched soil water condition. Soil moisture typically exceeds field capacity for long periods of the year with imperfect to very poorly drained and anaerobic soil conditions being prevalent. Subclass G_2 (i) is characterized by soils which are subjected to periodic inundation. Soil moisture and drainage conditions in these soils is complex and variable due to the temporal relationship between inputs and the response of the true groundwater table. However, the true groundwater table is generally close to the surface resulting in soils with moisture contents above field capacity and characterized by imperfect to very poor drainage.

APPENDIX IV

Ecosite Groups

Six ecosite groups and five subgroups have been recognized. A descriptive summary of the ecosite groups and subgroups is presented below:

Group a and Subgroup a(m) - Characterized by ecosites with exposed bedrock surfaces. Non-soil cover, i.e., unconsolidated material less than 10 cm in depth can occur and soil cover if present would be less than a 25% inclusion in the map unit. No differentiation on the basis of rock type or form is undertaken with the exception of subgroup a(m) which is separated on a morphological basis. This subgroup is characterized by oversteepened bedrock surfaces subject to natural geologic mass wasting. Talus and other unconsolidated products of mass wasting are an integral component of the subgroup. Drainage of these sites is primarily by means of surface runoff and is rapid to very rapid, thus restricting the development of perched groundwater or lateral seepage conditions.

Group b - Characterized by ecosites with negligible to low, short, simple and complex slope patterns. Parent materials are predominantly morainal and glaciofluvial but other genetic categories can be expected. These sites exhibit moderately well to very rapid drainage. Percolation is dominant on deep, coarse to moderately coarse textured soils. On thinner soils where bedrock restricts percolation, subsurface flow can occur at the soil rock interface. Such interflow is often discontinuous because of variability in soil depth and irregularity in the morphology of the bedrock substrate. The short slopes and complex slope patterns combined with the irregularity of the bedrock substrate effectively prevent the build-up of a continuous and dominant lateral seepage condition in these sites. Thus, group b is characterized by the G_o groundwater class.

Group c and Subgroups c(o); c(l) - Characterized by ecosites with negligible to low, short, simple and complex slope patterns. The dominant genetic categories in this group include morainal, alluvial and organic materials. Imperfect to very poorly drained conditions are dominant due to perched soil water or fluctuating true groundwater table. Perched soil water conditions develop in topographic basins where soil moisture accumulates and percolation is restricted by lithic contacts or impervious soil layers. In such areas evapotranspiration and drainage outputs are generally less than inputs from precipitation and runoff from the surrounding landscape. Thus the perched condition is characterized by saturated soils and moisture contents exceeding field capacity throughout the year. Fluctuating true groundwater tables are common on active floodplains which are subjected to periodic inundations. Subgroup c(o) is to be used with organic soils, whereas, subgroup c(l) is to be used with alluvial mineral soils.

Group d, and Subgroups d(o); d/d(o) - Characterized by ecosites with generally long simple slopes which promote a lateral downslope subsurface flow of soil water. The primary parent materials are morainal and/or colluvial having a variable textural range. Seepage of soil water is promoted by the presence of fragipans in the solum or by uniform and impervious bedrock substrate. Upper portions of the slope tend to be moderately well drained, whereas, middle and lower slope positions are imperfectly to

poorly drained due to a reduction of slope gradient and an accumulation of soil water. Subgroup d(o) is used to designate organic soil deposits which develop and are maintained on slopes by the presence of the lateral seepage of groundwater. Subgroup d/d(o) designates a complex of mineral and organic soils in which separation at the ecosite level is not practical.

Group e - Characterized by ecosites with short, simple and complex slope patterns. The primary parent materials are morainal deposits. These sites are moderately well to rapidly drained with no significant buildups of subsurface flow. The short steep slopes combined with the complex slope patterns, effectively restrict the development of dominant seepage of soil water. Thus, group e is characterized by the G_o groundwater class.

Group f - Characterized by ecosites with steep slopes and perched soil water or true groundwater tables. Such sites are unlikely to occur under natural conditions, since the prevailing slope conditions would restrict their development.